

**BIOLOGICAL INVENTORY AND ASSESSMENT OF  
TEN SOUTH RIMS SPRINGS IN GRAND CANYON NATIONAL PARK**

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## **EXECUTIVE SUMMARY**

### **INTRODUCTION**

Tonto Platform springs and seeps emanating from the Redwall Formation aquifer are some of Grand Canyon's most biologically diverse and productive ecosystems. Like everywhere in the arid Southwest, water is a much sought after commodity, and most of the West's springs have been severely altered or eliminated by ground water withdrawal, diversion, and manipulation of the source areas. Recent urban developments and wells drilled into the Coconino Plateau south of Grand Canyon may threaten the persistence of springs, particularly those derived from the Redwall aquifer on the south side of the Colorado River. Grand Canyon springs are important to the region's natural heritage for several reasons: 1) they provide critical water and food resources to wildlife and recreational hikers; 2) they are important point sources of biodiversity and productivity in otherwise low productivity desert landscapes; and 3) they are the focus of human activities, regional history, and land and wildlife management. Despite their ecological importance and policy relevance, the ecology of these natural water sources has not been systematically inventoried in Grand Canyon or elsewhere in the Southwest (Grand Canyon Wildlands Council 2002). This effort provides baseline information on the condition of these important ecosystems. Funding for this project was provided by the NPS and the Arizona Water Protection Fund.

Objectives in this program were to: 1) inventory the biotic characteristics of 10 springs emanating from the South Rim of Grand Canyon National Park to determine the existing range of diversity and to establish a baseline that may be used to measure long-term change; 2) characterize variation of springs flora and fauna; 3) relate site geomorphology and possibly water quality to riparian vegetation; and 4) provide recommendations to the NPS on monitoring and protection of these sites. Our information considerably augments previously collected data on Grand Canyon springs biota. In the following sections, we describe our methods and progress to date on the tasks for which we were responsible in this project.

### **PHYSICAL SITE CHARACTERISTICS**

#### **Study Area**

Ten South Rim springs studied here include: Cottonwood Creek Spring, East Grapevine Spring, Burro Spring, Pipe Creek Spring, Pumphouse Spring, Monument Creek Spring, Hermit Creek Spring and the Hermit Creek NPS streamflow gauge site; East Boucher Spring, Royal Arch Creek Spring at Falls #5, and Matkatamiba Alcove Spring. All of these springs emerge from the Cambrian Muav Limestone, with ground water presumably derived from the overlying Redwall Formation. Six site visits were made to each of these springs over the project duration, emphasizing spring and fall visits. Access to sites was via hiking trails, and an average of one day was spent at each site per visit. Royal Arch Creek Spring and Matkatamiba Alcove Spring were accessed primarily by river trips.

#### **Physical Site Measurements**

The geomorphic setting, site slope and aspect, and soil texture were observed and recorded on the study sites, and the location of each site were measured with a Garmin GPS unit. A sketchmap of each was made and surrounding features indicated on the map. Sites were photographed, and observations on recent changes were recorded.

The mean monthly solar radiation budget was measured using a solar pathfinder at each site. Solar radiation budgets of the 10 springs varied widely, with some sites strongly shaded by adjacent cliffs while others were less affected by shading (Tables 3, 4; Appendix A). The sites most strongly limited by cliff shading (e.g., Monument, Hermit and Royal Arch Creek springs) had one third the available solar flux of the more exposed sites (e.g., Cottonwood Creek and East Grapevine springs). Monument Creek Spring received <20% of ambient sunlight, whereas Cottonwood Creek Spring receive >90% of the ambient solar radiation.

## FLORA

We searched for all species of plants at each site, and the vegetation patches of the study area were mapped on the sketchmap. Vegetation cover was described by visually estimating the percent cover in 3 strata (ground cover, shrub cover and tree cover). Plant taxonomy follows that of the regional floras.

We detected 124 plant species among these 10 springs, of which 14 (16.7%) of 84 ground cover species were non-native, 2 of 44 (4.5%) of shrub species were non-native, and none of the tree species was non-native. The relatively high proportion of exotic ground covering flora demonstrates the strong invasion corridor effect in Grand Canyon riparian zones.

The number of vascular plant species/spring varied from a low of 16 at East Boucher Spring to a high of 45 at Cottonwood Creek Spring. Ground covering species were most abundant (8-28 species), followed by shrub diversity (4-19 species), and tree diversity was low (0-3 species), primarily Fremont cottonwood and Goodding willow. Given the small areas occupied by these springs (generally < 0.2 ha), springs plant species density is much higher than in the surrounding xeric uplands; however, understanding the role of springs as keystone ecosystems in desert landscapes will require additional research.

The grand mean percent vegetation cover varied greatly among these springs study sites: 20-94% for ground cover (mean = 50%), 19-96% for shrub cover (mean = 46%), and 0-45% (mean = 7%) for tree canopy cover. This large variation among sites was attributable to variation in geomorphology and solar energy budgets, from open, alluvial sites (e.g., Cottonwood Creek Spring) to narrow bedrock canyons (e.g., Monument and Hermit Creek springs). In addition, variation in vegetation cover among sites was attributable to the relatively high likelihood of flooding. Riparian and wetland vegetation that is subject to flooding is dominated by widespread, weedy species that are capable of rapid recolonization following floods. All of the springs in this study except Pumphouse Spring and, to a lesser extent, Burro Spring, existed in frequently flood-scoured channels, and therefore, it was not surprising that few rare, microsite-adapted plant species were detected. Monument Creek, Hermit Creek, Royal Arch Creek, Matkatamiba Alcove springs are extremely flood-prone, and are likely to undergo large seasonal changes in vegetation. Interannual variation in ground cover at Monument Creek Spring was extreme, varying from 12-73%, with an average of 37.3% cover and a standard deviation (31.0%) approaching the mean.

Calculation of relative importance values ( $RIV = \text{mean \% cover} \times \text{frequency}$ ) indicated that several species were both widely distributed and locally abundant. Cardinal monkeyflower (*Mimulus cardinalis*,  $RIV = 4.42$ ) and maiden-hair fern (*Adiantum capillus-veneris*, 4.00) had the highest RIVs but occurred primarily at bedrock-dominated springs that were subject to severe flood scouring (e.g., Monument Creek and Hermit Creek springs). *Muhlenbergia asperifolia* (3.75) and common reed (*Phragmites australis*, 3.12) were widely distributed among the more alluvial sites. Canadian goldenrod (*Solidago canadensis*) occurred at all study sites, but was less

locally abundant, and therefore had a somewhat lower RIV (1.82). A great many native subdominant taxa were detected, but of the non-native species, only *Bromus rubens* and *B. rigidus* (cheatgrasses) had RIVs >0.4. These two abundant winter annual species are threats because they may increase fire frequency by providing more dead ground cover during the early summer.

## FAUNA

### Invertebrates

Springs are rare habitats that support high biodiversity and serve as ecological and evolutionary refugia for aquatic invertebrates. Sites were visited twice/yr and a variety of techniques were used to sample the aquatic and terrestrial invertebrates in and around the selected springs during the 2000-2003 growing seasons, including aerial and kick netting, Surber sampling, black and white lighting, Malaise trapping, colored-pan trapping, and extensive spot sampling.

We detected 93 aquatic invertebrate taxa at these springs, with numerous new records for Arizona and Grand Canyon National Park. Several species of particular management significance are *Helichus*, especially *H. triangularis* (Coleoptera: Dropidae) appear to be common at springs sources and may serve as a useful indicator of flow perennality. *H. suturalis* was only found at East Grapevine Spring. We estimate that nearly 70% of the >80 aquatic beetles of the Grand Canyon region require springs or spring-fed streams, and occur in no other habitats. An isolated population of belostomatid giant water bugs (*Abedus h. herberti*) was found in Boucher Creek, and the ochterid bug (Hemiptera: Ochteridae, *Ochterus rotundus*) is only known from several Grand Canyon springs (including Royal Arch Creek) and central southern Mexico (Polhemus and Polhemus 1976). This species may warrant management attention (our specimens are still out for positive identification as of this writing). Several individuals of *Brechmorhoga mendax* (Libellulidae) collected at some of these springs (e.g., Monument and Hermit Creek springs) have a gunmetal blue face, an atypical feature for this taxon, and may be an endemic form. Stoneflies (Plecoptera) were oddly rare from these collections.

We identified 199 terrestrial invertebrate taxa, including several species new to science, new records for Arizona, new records for Grand Canyon National Park, and several species of potential management significance. A *Protolophus* (Protolophidae) harvestman at East Boucher Spring and a *Thiodina* salticid jumping spider near *T. sylvana* at Monument Creek Spring appear to be new to science. The Grand Canyon endemic tiger beetle, *Cicindela hemorrhagica arizonae* occurs as a riparian obligate species along perennial streams in the upper and middle Grand Canyon, particularly Hermit, Monument and Boucher creeks. No endangered landsnails were detected at these 10 springs. Among the 16 species of butterflies and skippers found at these 10 Grand Canyon springs, we detected four species not previously reported from Grand Canyon, including the hesperiid Arizona powdered-skipper (*Systacea xampa*), the endemic megathymid piute agave skipper (*Agathymus alliae piute*), as well as the desert marble (*Euchloe lotta*) and desert elfin (*Callophrys fotis*).

Spring-fed riparian zones provide far richer habitat than do the surrounding landscape, a fact well known for plants and, but less well recognized for invertebrates. Butterfly distribution clearly demonstrated the keystone role of springs ecosystem in this desert landscape. We observed up to 4.3-fold higher species richness and >300-fold greater abundance of butterflies and skippers along spring-fed streams than in the surrounding desert landscape.

## Vertebrates

We detected 6 amphibian and reptile species at the springs study sites. The two common amphibians included the red-spotted toad (*Bufo punctatus*) and canyon treefrog (*Hyla arenicolor*). The former was more abundant along low-gradient spring-fed streams, such as Cottonwood Creek, East Grapevine, Pipe Creek, and Hermit Creek springs, while the latter was more abundant near spring sources in bedrock and cobble/boulder stream reaches, such as cliff-bound reaches of Cottonwood Creek, East Boucher, Hermit Creek, and Matkatamiba Alcove springs. The lizards encountered were typical of middle and low elevations for Grand Canyon (Table 9), and included side-blotched lizard (*Uta stansburiana*), tree lizard (*Urosaurus ornatus*), desert spiny lizard (*Sceloporus magister*), western whiptail (*Cnemidophorus tigris*), collared lizard (*Crotaphytus bicinctores*), and banded gecko (*Coleonyx variegatus*). We encountered Grand Canyon pink rattlesnakes (*Crotalus viridis abyssus*) at Burro Spring and Matkatamiba Alcove Spring.

We detected 44 bird species at the springs studied here. Avian use of these 10 springs was generally high, with primary use as water sources. A total of 18 (41%) of the bird species detected at springs were not observed in the adjacent desert uplands, similarly attesting to the keystone landscape function of these desert springs. Neither southwestern willow flycatcher (*Empidonax trailii eximius*), yellow-billed cuckoo (*Coccyzus americanus*), nor any rail species were detected at any of these springs; however, at least one avian species of management concern was found. Mexican spotted owls (*Strix occidentalis*) were detected at Cottonwood Creek Spring, near East Boucher Spring, and in Matkatamiba Canyon. This species is of considerable management concern in the Park. In addition, we found an American dipper nest (*Cinclus mexicanus*) in Matkatamiba Creek, near the Matkatamiba Alcove Spring. This late April nest is the only one reported in Grand Canyon in a desert warmwater stream (Stevens et al. 1997).

Few mammals were detected through direct observation at the 10 springs, primarily because most desert mammals are nocturnal, and because larger mammals are wary of humans. We occasionally saw, or otherwise detected sign, of desert bighorn sheep (*Ovis canadensis nelsoni*) and desert mule deer (*Odocoileus hemionus*), woodrat (*Neotoma* spp.) and rock squirrel (*Ammospermophila variegatus*), as well as bats, but we did not net or otherwise sample for bats.

Small mammal live-trapping was conducted at all sites during spring and fall visits, using >50 Sherman live traps/night/site. All specimens were identified, sexed, weighed, and reproductive status recorded by date. Trap success varied widely, from 0-67.5%, with low trap success during and after drought years (2000 and 2002). Springs support different assemblages and abundances of small mammal than exist at lower elevations along the Colorado River. *Neotoma*, *Eutamias*, *Peromyscus* (especially *P. boylei* and *P. eremicus*) were common at springs along the Tonto Platform, whereas *Peromyscus eremicus*, *Peromyscus crinitus*, and *Neotoma lepida* are more abundant along the Colorado River. Springs may serve as low elevation refugia for some species that are otherwise found at higher elevations on the South Rim, such as brushy-tailed woodrats (*Neotoma cinerea*) and chipmunks (*Eutamias dorsalis*).

## VEGETATION – ENVIRONMENT RELATIONSHIPS

We analyzed the importance of springs ecosystem geomorphic setting and area sampled to determine the role of these two factors on plant species alpha diversity among the 10 sites studied. The number of plant species encountered at each spring varied positively as a function of the size of the spring area sampled, and negatively in relation to the geomorphic flood

disturbance intensity. Correlations between plant species richness with aspect and elevation were not strong, a result of too little variation in these variables. Similarly, insufficient variation in water quality exists to evaluate its impact on floral or faunal composition at springs. Much additional data from other springs are required to investigate these relationships.

We examined the role of beta diversity on springs flora by determining the elevation range of all vascular plant taxa in the region and analyzing range exceedances. A total of 11 (10.2%) of the 108 plant species for which elevation range data were available exceeded their range limits at these 10 Grand Canyon springs. This indicates that although the springs studied supported few endemic plant species (*Flaveria macdougallii* in MAS was an exception), the plant assemblages represented at these springs were relatively unique. Six species ranges extended down to these springs from higher elevations, while five species were found beyond the top of their published elevational ranges at the springs. Cottonwood Creek, East Grapevine, and Pipe Creek Spring each supported four plant species that existed beyond their normal elevational ranges, and Monument Creek Spring supported three such species.

We hypothesized that highly protected, north-facing springs would support a higher proportion of upper elevation species. This was partially supported by the presence of *Betula occidentalis* at Monument Creek Spring, and high elevation *Carex* spp. and *Vicia* at Cottonwood Creek and East Grapevine springs. However, the study sites also contained nearly equal numbers of low elevation species that reached their highest elevations at these springs. Plant composition is complicated by longitudinal boundaries, affecting east-west distribution of species. For example, *Iva acerosa* reaches its western limit at Pipe Creek Spring, while *Flaveria macdougallii* reaches its eastern boundary at Colorado River Mile 136.5L.

## **MANAGEMENT AND MONITORING RECOMMENDATIONS**

We discuss criteria involved in monitoring and management of Grand Canyon springs, and we recommend that the NPS at Grand Canyon collaborate with Mohave and other National Park Service units on the Colorado Plateau, which are actively discussing protocols for long-term monitoring of springs. With the caveats and guidelines presented here, this collaboration should provide the necessary management strategies and monitoring protocols, including data management protocols, needed for the NPS to fulfill its mission with regard to resource protection and visitor satisfaction.

## INTRODUCTION

Springs emanating from the South Rim of Grand Canyon National Park are important to the region's natural heritage for several reasons: 1) they provide critical water and food resources to wildlife and recreational hikers; 2) they are important point sources of biodiversity and productivity in otherwise low productivity desert landscapes; and 3) they are the focus of human activities, regional history, and land and wildlife management. Despite their ecological importance and policy relevance, the ecology of natural water sources has, with few exceptions, been systematically inventoried in Grand Canyon or elsewhere in the Southwest (Grand Canyon Wildlands Council 2002). The Grand Canyon Wildlands Council (GCWC) assisted the National Park Service (NPS) and the U.S. Geological Survey (USGS) by undertaking the biological inventory of 10 South Rim springs from 2000 to 2003. This effort provides baseline information on the condition of these important ecosystems. Funding for this project was provided by the Arizona Water Protection Fund, an office of the Arizona Department of Water Resources, and Grand Canyon National Park..

GCWC's objectives in this program were to: 1) inventory and map the location and biotic characteristics of 10 springs emanating from the South Rim of Grand Canyon National Park to determine the existing range of diversity and to establish a baseline that may be used to measure long-term change; 2) characterize the seasonal responses of springs flora and fauna; 3) relate site geomorphology and water quality to riparian vegetation; and 4) provide recommendations to the NPS on monitoring and protection of these sites. Our information considerably augments previously collected data on Grand Canyon springs biota. In the following sections, we describe our methods and progress to date on the tasks for which we were responsible in this project.

## TASK #2: PUBLIC OUTREACH

We assisted with editing and design recommendations on the NPS poster on Grand Canyon springs in 2001-2002, and L.E. Stevens prepared a news release on the 10 South Rim springs ecosystems under study here. We also advised Ms. A.W. Walka on aspects of springs ecology for her article in Plateau Magazine in 2001.

## TASK #5: MACROPHYTIC VASCULAR PLANT DISTRIBUTION METHODS

### Study Area

Ten South Rim springs studied here include: Cottonwood Creek Spring, East Grapevine Spring, Burro Spring, Pipe Creek Spring, Pumphouse Spring, Monument Creek Spring, Hermit Creek Spring and the Hermit Creek NPS streamflow gauge site; East Boucher Spring, Royal Arch Creek Spring at Falls #5, and Matkatamiba Alcove Spring (Table 1, Fig. 1). All of these springs emerge from the Cambrian Muav Limestone, with ground water presumably derived from the overlying Redwall Formation. Six site visits were made to each of these springs over the project duration, emphasizing spring and fall visits. Access to sites was via hiking trails, and an average of one day was spent at each site per visit. Royal Arch Creek Spring and Matkatamiba Alcove Spring were accessed primarily by river trip.

## RESULTS – PHYSICAL SITE MEASUREMENTS

***Slope and Aspect:*** Site slope and aspect were measured on the study sites, and the location of each site were measured with a Garmin GPS unit (Table 2; Appendix A). These spring sources were mapped in greater detail by the U.S. Geological Survey and the NPS.



Table 1: Springs study site visits from 2000-2003 to the Grand Canyon springs emanating from the Redwall aquifer on the Tonto Platform, Grand Canyon National Park, Grand Canyon, Arizona.

Site	Abbreviation	Site Visits						
		Date 1	Date 2	Date 3	Date 4	Date 5	Date 6	Other
Cottonwood Creek Spr	CCS	24-Apr-00:	22-Oct-00	30 Mar-01:m,s	29-Apr-01:	17-Jul-01:	26-Oct-01:m	22-Sep-02; 20-Mar-03;
Cottonwood Creek Gauge	CCG	24-Apr-00:	22-Oct-00	30 Mar-01:m,s	29-Apr-01:	17-Jul-01:	26-Oct-01:m	22-Sep-02; 20-Mar-03;
East Grapevine Spr	EGS	23-Apr-00:	22-Oct-00:	28-Mar-01:m,s	30-Apr-01:	19-Jul-02:	26-Oct-01:m	22-Sep-02; 22-Mar-03:
Burro Spr	BS	19-Apr-00:	30-Apr-00:	3-Jul-01:	24-Sep-01:m	6-Sep-02:m	31 Dec.02:s	24 May-03:
Pipe Creek Spr	PCS	20-Apr-00:	30-Apr-00:	7-Jul-01:	24-Sep-01:m	6-Sep-02:m	31 Dec.02:s	25 May-03:
Pumphouse Spr	PHS	29-Aug-00:	7-Jul-01:	15-Nov-01:m	4 May-02:m	4-Jun-02:	12-Aug-02:	20-Sep-02; 31 Dec.02:s
Monument Creek Spr	MCS	9-Sep-00:	15-Jun-01:	28-Jul-01:	27-Nov-01:m	15-Jun-02:m	18-Sep-02:s	
Hermit Creek Spr	HCS	30-Aug-00:	13-Jun-01:	27-Jul-01:	24-Sep-01:	13-Jun-02	17-Sep-02:s	
Hermit Creek Gauge	HCG	30-Aug-00:	14-Jun-01:	27-Jul-01:	24-Sep-01:m	13 Jun-02:m	17-Sep-02:s	4-Apr-03:
East Boucher Creek Spr	EBS	29-Aug-00:	31-Mar-01:m,s,p	27-Sep-01:m	2-Oct-01:	30-Sep-02:	2-Apr-03:	
Royal Arch Cr. Spr, Falls #5	RAS	11-Mar-00:	2-Apr-01:s	8-May-01:	30 Sep.-01:	28-Apr-02 :m	2 May-02:	2 May-03:m
Matkatamiba Alcove Spr*	MAS	13-Mar-00:	9-June-00:	4-Apr-01:s	9-May-01:	29-Sep-01:m	29-Apr-02:	3-May-03:m

KEY: m-mammal trapping

s-solar pathfinder

Table 2: Georeferencing data for the South Rim springs. These data are approximate: more refined data are available from the U. S. Geological Survey.

Site	N	W	GPS Accuracy (m)	Approx. Elev (m)	Mean Dip Angle	Aspect (TN )
Cottonwood Creek Spring	36.14050	111.59285	5	1150	2	13
East Grapevine Spring	36.25380	112.08100	4	1100	6	323
Burro Spring	36.07019	112.09895	7	1120	3	261
Pipe Creek Spring	36.07091	112.10164	8	1135	2	325
Pumphouse Spring	36.46770	112.75460	11	1170	6	313
Monument Creek Spring*	12S 393752	UTM 3992742	5	1150	70	328
Hermit Creek Spring	36.04003	112.13401	5	1170	80	13
Hermit Creek NPS Gauge	36.04837	112.12849	8	900	5	15
East Boucher Spring	36.59980	112.14186	9	1077	35	83
Royal Arch Spring@Falls#5*	36.27158	112.52636	---	700	80	280
Matkatamiba Alcove Spring*	36° 20.5'	112° 40.5'	---	560	11.5	73

\* Overhanging cliffs prevent accurate GPS measurements.



## Grand Canyon National Park Springs

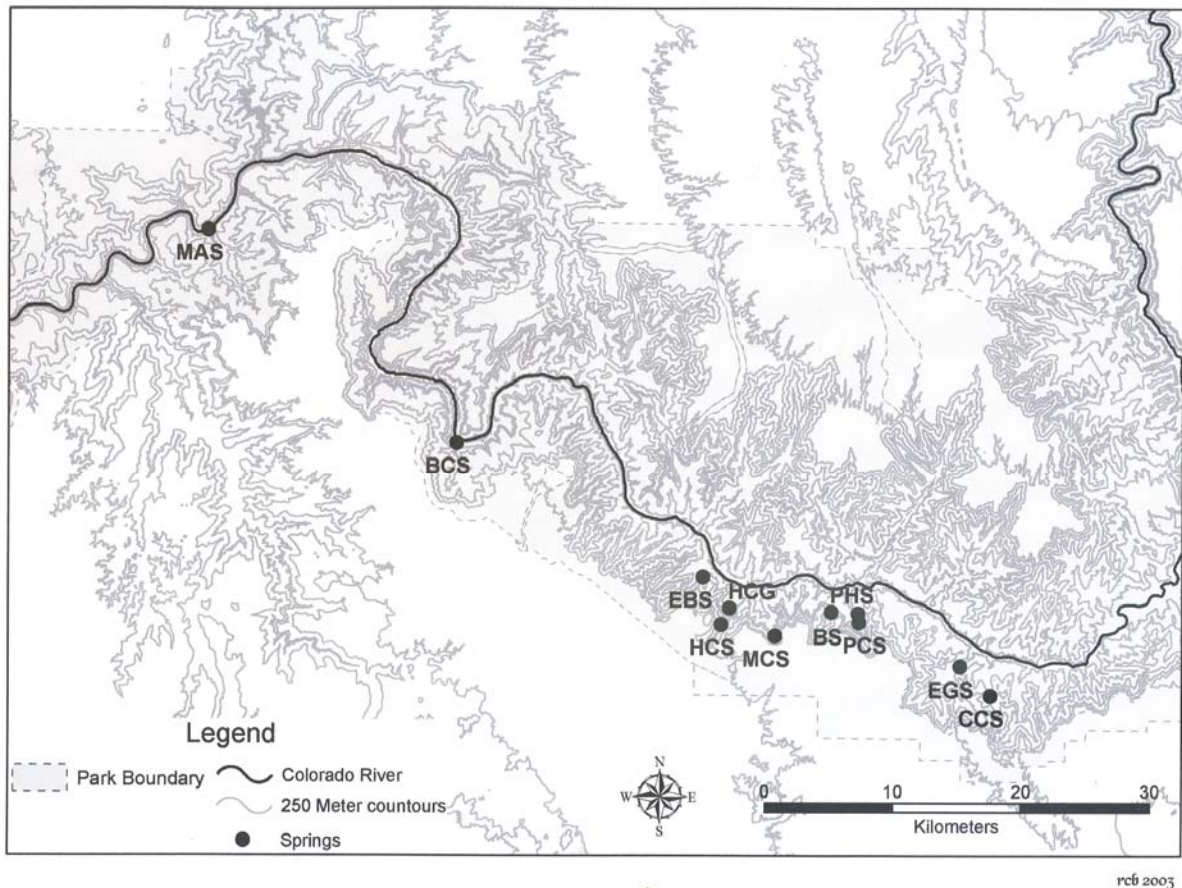


Figure 1: Locations of the Grand Canyon springs emanating from the Redwall Formation on the Tonto Platform, Grand Canyon National Park, Arizona. See Table 1 for abbreviations of springs study site names.

**Solar Radiation Budget:** Solar radiation measurements may strongly affect vegetation growth and composition in relation to slope aspect, a little-studied factor affecting plant communities throughout the Southwest. The mean monthly duration of direct radiation at each site was measured using a Solar Pathfinder (SPF; Solar Pathfinder, Inc. 1994; Solar Pathfinder, Inc. 2000), and were used to develop an annual solar energy budget for each site. The solar energy budget is important to springs, seeps and natural ponds because aspect influences important physical properties of the study sites, such as temperature, the amount of light available for photosynthesis by wetland vegetation, the duration of freezing in winter, and evaporation and relative humidity in the summer months. The SPF consists of a reflective, transparent dome mounted over a template of the percent of mean monthly solar radiation intercepted on a flat surface within half-hour intervals between sunrise and sunset for each month. The device provides estimates of the mean monthly flux (Mj/mo) and percent of unobstructed ambient direct solar radiation received at a given location (Tables 3, 4; Appendix A).

Table 3: Mean monthly solar radiation flux (Mj/mo) at 10 springs and two streamflow gauge sites, Grand Canyon, Arizona. Seasonal and annual sums are provided at the bottom of the table.

Period	Mean monthly flux (Mj/mo)											
	CCG	CCS	EGS	Burro	PCS	PHS	MCS	HCS	HCG	EBS	RAS	MAS
Dec	207.6	190.3	155.7	173.0	132.7	173.0	0.0	0.0	190.3	46.1	0.0	0.0
Jan	238.1	222.2	209.5	203.1	139.7	203.1	0.0	0.0	203.1	47.6	0.0	0.0
Nov	264.9	247.3	233.2	226.1	155.4	226.1	0.0	0.0	250.8	81.2	0.0	0.0
Feb	341.9	293.6	305.7	285.6	249.4	285.6	0.0	72.4	277.5	168.9	0.0	0.0
Oct	466.0	408.4	403.2	397.9	403.2	397.9	0.0	94.3	361.3	219.9	0.0	0.0
Mar	562.9	503.0	521.0	491.1	479.1	497.0	0.0	143.7	407.2	323.4	35.9	155.7
Sep	628.0	561.2	581.2	587.9	567.8	587.9	80.2	160.3	494.4	400.8	40.1	347.4
Apr	707.7	670.1	692.7	692.7	655.0	692.7	143.1	233.4	640.0	451.7	301.2	391.5
Aug	770.5	714.3	778.5	738.4	738.4	738.4	192.6	208.7	682.2	545.8	377.2	473.5
May	852.8	870.9	880.0	852.8	816.5	852.8	308.5	290.3	771.1	662.3	417.3	626.0
Jul	833.3	859.9	859.9	833.3	797.8	833.3	328.0	283.7	788.9	647.1	407.8	611.7
Jun	840.9	868.3	868.3	850.1	804.4	850.1	347.3	347.3	795.2	649.0	466.2	612.4
Winter	787.6	706.1	670.9	661.8	521.7	661.8	0.0	72.4	671.0	262.7	0.0	0.0
Spring	2123.5	2044.1	2093.7	2036.5	1950.6	2042.5	451.5	667.4	1818.3	1437.4	754.4	1173.2
Summer	2444.7	2442.5	2506.7	2421.7	2340.6	2421.7	868.0	839.7	2266.4	1841.9	1251.2	1697.6
Autumn	1358.9	1216.9	1217.5	1211.9	1126.5	1211.9	80.2	254.6	1106.5	702.0	40.1	347.4
Col. Totals	6714.7	6409.6	6488.9	6331.9	5939.4	6337.9	1399.6	1834.1	5862.2	4244.0	2045.7	3218.2

Table 4: Mean monthly percent solar radiation flux in relation to clear-horizon ambient conditions at 10 springs and two streamflow gauge sites, Grand Canyon, Arizona. Seasonal averages and annual percent are provided at the bottom of the table.

Period	Mean monthly percent flux in relation to clear horizon ambient conditions											
	CCG%	CCS%	EGS%	Burro%	PCS%	PHS%	MCS%	HCS%	HCG%	EBS%	RAS%	MAS%
Dec	72.0	66.0	54.0	60.0	46.0	60.0	0.0	0.0	66.0	16.0	0.0	0.0
Jan	75.0	70.0	66.0	64.0	44.0	64.0	0.0	0.0	64.0	15.0	0.0	0.0
Nov	75.0	70.0	66.0	64.0	44.0	64.0	0.0	0.0	71.0	23.0	0.0	0.0
Feb	85.0	73.0	76.0	71.0	62.0	71.0	0.0	18.0	69.0	42.0	0.0	0.0
Oct	89.0	78.0	77.0	76.0	77.0	76.0	0.0	18.0	69.0	42.0	0.0	0.0
Mar	94.0	84.0	87.0	82.0	80.0	83.0	0.0	24.0	68.0	54.0	6.0	26.0
Sep	94.0	84.0	87.0	88.0	85.0	88.0	12.0	24.0	74.0	60.0	6.0	52.0
Apr	94.0	89.0	92.0	92.0	87.0	92.0	19.0	31.0	85.0	60.0	40.0	52.0
Aug	96.0	89.0	97.0	92.0	92.0	92.0	24.0	26.0	85.0	68.0	47.0	59.0
May	94.0	96.0	97.0	94.0	90.0	94.0	34.0	32.0	85.0	73.0	46.0	69.0
Jul	94.0	97.0	97.0	94.0	90.0	94.0	37.0	32.0	89.0	73.0	46.0	69.0
Jun	92.0	95.0	95.0	93.0	88.0	93.0	38.0	38.0	87.0	71.0	51.0	67.0
Winter	77.3	69.7	65.3	65.0	50.7	65.0	0.0	6.0	66.3	24.3	0.0	0.0
Spring	94.0	89.7	92.0	89.3	85.7	89.7	17.7	29.0	79.3	62.3	30.7	49.0
Summer	94.0	93.7	96.3	93.0	90.0	93.0	33.0	32.0	87.0	70.7	48.0	65.0
Autumn	86.0	77.3	76.7	76.0	68.7	76.0	4.0	14.0	71.3	41.7	2.0	17.3

Total	90.6	86.4	87.5	85.4	80.1	85.5	18.9	24.7	79.1	57.2	27.6	43.4
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Three measurements were made per reading and averaged to relate the effect of shading on spring's vegetation and species composition. The instrument was calibrated against actual sunrise and sunset times and found to be accurate within approximately a 5-m radius and within 40 minutes/month (GCWC 2002).

The solar radiation budget of the 10 springs varied widely, with some sites strongly shaded by adjacent cliffs while others were less affected by shading (Tables 3, 4; Appendix A). The sites most strongly limited by cliff shading (e.g., Monument, Hermit and Royal Arch Creek springs) had one third the available solar flux of the more exposed sites (e.g., Cottonwood Creek and East Grapevine springs). Monument Creek Spring received <20% of ambient sunlight, whereas Cottonwood Creek Spring receive >90% of the ambient solar radiation.

**Site Documentation:** A sketch map was made of each spring, identifying prominent features, photo points, and the solar pathfinder location, and photographs of the site were taken to provide documentation of site conditions during the period of study (e.g., Fig. 2; Appendix B). Photo points were situated in relation to fixed objects, such as ledges or large rocks, where possible. Photo points were photographed or sketched on the site map, as appropriate to the site conditions. Photo points were indicated on the vegetation data sheet associated with the site. Two site photo(s) were taken, where possible, approximately 45° apart, for potential future use in mapping or site evaluation. Photographs were acquired using a 38-105 zoom camera with ASA 200 color print film, or with a digital camera, and according to AWPf protocols. Photos were electronically scanned and are included in electronic form for future reference (Appendix B).

**Field Soil Measurements:** Soils provide information on site productivity through inclusion of organic matter, as well as information on grain size, pH and moisture levels, all of which are related to vegetation structure, composition and germination potential. However, the NPS declined permission to collect soils before archeological clearance has been performed on these sites. Instead of chemico-physical measurements, we visually estimated surficial soil texture on vegetation polygons, and documented the extent of the wetted area, where possible.

We recommend that the NPS subject these sites to more intensive archeological analysis and then engage in a detailed analysis of springs soils. Such an effort should also include analysis of nutrient dynamics, as well as fossorial arthropods, which are likely to be of interest to the Park's bioinventory and cannot be collected without sampling soils and installing pitfall traps.

**Laboratory Soil Analyses:** Because no soils were collected, we did not conduct laboratory soil analyses.

**Vegetation Cover Mapping:** The site sketch map (e.g., Fig. 2) was used to measure and monitor the distribution and composition of vegetation patches, cardinal orientation, slope angle, as well as the location of landmarks, photo points, soil texture, and SPF readings.

Wetland and riparian vegetation were mapped at each spring, following the methods of Bonham (1989) and the Grand Canyon Wildlands Council (GCWC). GCWC (2002) conducted similar mapping at 103 springs, seeps and natural ponds on the Arizona Strip, and the data presented here are compatible with the Arizona Strip data. Our initial site visits in 2000 revealed that it is more accurate, cost-efficient, and less damaging to the study site, to measure,



map, and characterize the overall dimensions of vegetation patches than to use individual plot analyses. We measured the size and orientation of each major patch of vegetation around the spring, including a visual estimate of the cover of all plant species to the nearest 5%, including ground cover (non-perennial and <1 m in height), shrub cover (woody perennial  $\leq$  4 m in height), and tree canopy (perennial, woody and >4 m in height) species. Composition by cover was recorded for each patch, including aquatic, wetland and riparian species, using visual releveé estimation of percent cover (VRE%*C*). Aquatic macrophyte cover, where it existed, was mapped on the sketch map, using the same methods as those used for riparian vegetation. Algal samples were collected where found and have been preserved for NPS analyses, should the agency so desires.

Patch descriptions included microsite geomorphology, soil conditions, dip angle and aspect (Table 2; Appendices A, B). The vegetation surrounding the site outside of the vicinity of the spring was described (Tables 5-7, Appendix C). Percent cover and species richness by cover type were measured or estimated. Plant taxonomy follows that of the regional floras, including Phillips et al. (1987), Welsh et al. (1987), Hickman (1993), Ayers et al. (1994), and Brian et al. (submitted). We searched intensively for all species of plants on each site visit. One to four individuals or diagnostic portions of any unrecognized plants were collected, and all taxa detected will be recorded in field notes as well. Plants specimens are being held at the herbaria of Northern Arizona University or the Museum of Northern Arizona, and a voucher specimen of each species is being prepared for submission to the NPS herbarium.

## **RESULTS - VEGETATION**

### **Diversity and Composition**

A total of 124 plant species were detected at the springs study areas, of which 14 (16.7%) of 84 ground cover species were not native, 2 of 44 (4.5%) of shrub species were exotic, and none of the tree species was non-native (Tables 5, 6; Appendix C). The relatively high proportion of exotic ground covering flora demonstrates a strong invasion corridor effect in Grand Canyon riparian systems (Stevens and Ayers 2002).

The number of vascular plant species/spring varied from a low of 16 at East Boucher Spring to a high of 45 at Cottonwood Creek Spring. Ground covering species were most abundant (8-28 species), followed by shrub diversity (4-19 species), and tree diversity was low (0-3 species), primarily Fremont cottonwood and Goodding willow. Given the small areas occupied by these springs (generally < 0.2 ha), springs plant species density is much higher than in the surrounding xeric uplands.

The mean total percent vegetation cover varied greatly among these springs study sites: 20-94% for ground cover (mean = 50%), 19-96% for shrub cover (mean = 46%), and 0-45% (mean = 7%) for tree canopy cover. This large variation among sites was attributable to variation in geomorphology and solar energy budgets (Tables 5, 6; Stevens et al. 1995), from open, alluvial sites (e.g., Cottonwood Creek Spring) to narrow bedrock canyons (e.g., Monument and Hermit Creek springs). In addition, variation in vegetation cover among sites was attributable to the relatively high likelihood of flooding. Riparian and wetland vegetation that is subject to flooding is dominated by widespread, weedy species that are capable of rapid recolonization following floods. All of the springs in this study except Pumphouse Spring and, to a lesser extent, Burro Spring, existed in frequently flood-scoured channels, and therefore, it was not surprising that few rare, microsite-adapted plant species were detected. Springs that emerge from alluvial channel floors (e.g., Cottonwood Creek, Pipe Creek,

Table 5: Mean percent cover of plant species detected at the Grand Canyon springs, 2000-2003. Strata include: GC – ground cover (deciduous annual or perennial herb, forb, and graminoid, usually < 1m tall), SC – shrub cover (1-4 m perennial non-deciduous), and TC – tree cover (>4 m).

Genus	Species	Stratum	CCS	EGS	Burro Sp	PCS	PHS	MCS	HCS	HCG	EBS	RAS5
<i>Acourtia</i>	<i>wrightii</i>	GC						0.001				
<i>Adiantum</i>	<i>capillus- veneris</i>	GC			0.16	0.02		19.31	2.04		2.65	41.04
<i>Agrostis</i>	<i>stolonifera</i>	GC				5.00		7.40				
Algae	Algae spp	GC										
<i>Andropogon</i>	<i>glomeratus</i>	GC								16.97		
<i>Apocynum</i>	<i>canabinum</i>	GC			0.20							
<i>Aquilegia</i>	<i>chrysantha</i>	GC						0.40				
<i>Aristida</i>	<i>glauca</i>	GC		0.00		0.31						
<i>Artemesia</i>	<i>ludoviciana</i>	GC	0.01	0.06				0.001		0.01		
<i>Aster</i>	<i>canescens?</i>	GC	0.33									
<i>Aster</i>	sp.	GC			0.83						1.24	
<i>Astragalus</i>	<i>lentiginosus</i>	GC						0.001				
<i>Baccharis</i>	<i>emoryi</i> (seedling)	GC	2.50	0.23								
<i>Baccharis</i>	<i>salicifolia</i>	GC						0.001				
<i>Bothriochloa</i>	<i>barbinoides</i>	GC	4.00									
<i>Bouteloua</i>	<i>curtipendula</i>	GC	0.00	0.14								
<i>Bromus</i>	<i>rigidus</i>	GC			1.79		10.88		3.42		0.02	
<i>Bromus</i>	<i>rubens</i>	GC	0.33	1.10	5.22	0.19		0.001				0.51
<i>Bromus</i>	<i>tectorum</i>	GC	0.34	0.76				0.001				
<i>Bromus</i>	sp.	GC				0.61						
<i>Calamogrostis</i>	<i>scopulorum</i>	GC					4.40					
<i>Carex</i>	<i>aquatilis</i>	GC				2.50						
<i>Carex</i>	<i>atherodes?</i>	GC		1.82								
<i>Carex</i>	<i>aurea</i>	GC		1.67								
<i>Carex</i>	<i>geophila</i>	GC	2.00	0.07								
<i>Carex</i>	<i>hystericina</i>	GC	1.60	2.45	2.13	3.98						
<i>Carex</i>	<i>nebraskensis</i>	GC					11.57					

Genus	Species	Stratum	CCS	EGS	Burro Sp	PCS	PHS	MCS	HCS	HCG	EBS	RAS5
<i>Carex</i>	<i>specuicola</i>	GC									0.15	
<i>Carex</i>	sp.	GC						0.56				
<i>Centaurea</i>	<i>calycosum</i>	GC		0.00								
<i>Castelleja</i>	sp.	GC	0.33									
<i>Chara</i>	sp.	GC							4.71			
<i>Cirsium</i>	<i>arizonensis</i>	GC	0.01	0.70		0.001		0.90	0.01		0.33	
<i>Cladophora</i>	<i>glomerata</i>	GC				1.67			1.27			
<i>Clematis</i>	sp.	GC			0.09		1.17					
<i>Conyza</i>	<i>canadensis</i>	GC										7.68
<i>Datura</i>	<i>wrightii</i>	GC					0.000					
<i>Dichanthelium</i>	<i>languinosum</i>	GC	0.67			1.72		0.09				
<i>Elymus</i>	<i>canadensis</i>	GC	2.58									
<i>Elymus</i>	<i>cinereus?</i>	GC			1.86							
<i>Epipactus</i>	<i>gigantea</i>	GC	0.67			0.15						
<i>Equisetum</i>	<i>hymale x laevigatum</i>	GC	0.003		0.06					0.61		
<i>Pseudognaphalium</i>	<i>stramineum</i>	GC										0.01
<i>Hedeoma?</i>	sp.	GC						0.00				
<i>Hilaria</i>	<i>jamesii</i>	GC					0.85					
<i>Hilaria</i>	<i>rigidus</i>	GC										
<i>Hordeum</i>	<i>jubatum</i>	GC					0.39					
<i>Imperata</i>	<i>brevifolia</i>	GC								5.00		
<i>Juncus</i>	<i>bufonius</i>	GC		0.00								
<i>Lactuca</i>	<i>seriola</i>	GC	0.67	0.72								0.01
<i>Lepidium</i>	sp.	GC										
<i>Lobelia</i>	<i>cardinalis</i>	GC				0.34				0.00		
<i>Macraenthera</i>	sp.	GC						0.00				
<i>Maurandya</i>	<i>antirrhinifolium</i>	GC							0.16			0.02
<i>Mentha</i>	<i>arvense</i>	GC	0.03									
<i>Mentzelia</i>	<i>albomarginatus</i>	GC										
<i>Mimulus</i>	<i>cardinalis</i>	GC						31.30	5.62	2.00	9.41	36.86
<i>Moss</i>	sp	GC	0.33	0.25	0.54		0.54	4.31	1.40		0.22	1.22
<i>Muhlenbergia</i>	<i>asperifolia</i>	GC	5.45	16.90	1.10	5.14		0.00	0.50	16.07		0.51

<i>Muhlenbergia</i>	<i>porteri</i>	GC										0.51
Genus	Species	Stratum	CCS	EGS	Burro Sp	PCS	PHS	MCS	HCS	HCG	EBS	RAS5
<i>Rorippa</i>	<i>nasturtium-aquaticum</i>	GC					0.06		1.26			
<i>Nicotina</i>	<i>obtusifolia</i>	GC										0.01
<i>Oenothera</i>	<i>hookeri</i>	GC	0.84		0.32	0.84						
<i>Phragmites</i>	<i>australis</i>	GC			1.18	32.00	59.29			1.82		
<i>Poa</i>	<i>fendleriana</i>	GC	0.00									
<i>Poa</i>	<i>pratensis</i>	GC					0.66					
<i>Polypogon</i>	<i>monspeliensis</i>	GC		10.06								
<i>Schizachyrium</i>	<i>scoparium</i>	GC	0.67				1.04					
<i>Schaenoplectus</i>	<i>acutus</i>	GC	5.53									
<i>Solanum</i>	<i>sp.</i>	GC										3.20
<i>Solidago</i>	<i>canadensis</i>	GC	5.33	2.57	0.47	1.18	0.72	0.35	0.66	3.00	5.66	0.06
<i>Sonchus</i>	<i>asper</i>	GC		0.07								0.01
<i>Sphaeralcea</i>	<i>ambigua</i>	GC					0.00					
<i>Sporobolus</i>	<i>contractus</i>	GC		0.00								
<i>Sporobolus</i>	<i>flexuosus</i>	GC		0.31	0.63							
<i>Stipa</i>	<i>commata</i>	GC			1.55		1.82					
<i>Tamarix</i>	<i>pentandra</i>	GC						0.05				
<i>Thelepodium</i>	<i>integrifolium</i>	GC	0.17	0.55	3.47							
<i>Typha</i>	<i>domingensis</i>	GC		5.75		4.54				0.01		
<i>Verbascum</i>	<i>thapsus</i>	GC			0.17							
Unknown dicot sdl	<i>sp.</i>	GC	0.04					0.00	0.01			
Unk. grass	<i>perennial</i>	GC	0.10	0.31	4.72				0.01			
<i>Vicia</i>	<i>americana</i>	GC	2.33			0.50						
<i>Sidalcea?</i>	<i>sp.</i>	GC						0.01				
<i>Acacia</i>	<i>greggii</i>	SC			2.01			0.33		0.61		
<i>Agave</i>	<i>utahensis</i>	SC	0.33	2.63	0.09	0.01	1.78	0.00				
<i>Amelanchior</i>	<i>utahensis</i>	SC	0.67					0.46				
<i>Artemesia</i>	<i>tridentata</i>	SC	0.00									
<i>Aster</i>	<i>sp.</i>	SC				0.61	0.56					
<i>Atriplex</i>	<i>canescens</i>	SC		0.30								
<i>Baccharis</i>	<i>emoryi</i>	SC	28.27	1.30	1.05	16.08	12.87		0.03	6.97	0.88	
<i>Baccharis</i>	<i>salicifolia</i>	SC							2.03			7.43



<i>Stanleya</i>	<i>pinnata</i>	SC										
<b>Genus</b>	<b>Species</b>	<b>Stratum</b>	<b>CCS</b>	<b>EGS</b>	<b>Burro Sp</b>	<b>PCS</b>	<b>PHS</b>	<b>MCS</b>	<b>HCS</b>	<b>HCG</b>	<b>EBS</b>	<b>RAS5</b>
<i>Tamarix</i>	<i>pentandra</i>	SC		2.40		3.50				0.01		
<i>Vitis</i>	<i>arizonica</i>	SC					2.43					
<i>Juniperus</i>	<i>osteosperma</i>	TC	0.50									
<i>Populus</i>	<i>fremontii</i>	TC	22.25		4.00	19.02	7.07					
<i>Salix</i>	<i>gooddingii</i>	TC	22.42									

Table 6: Summary of plant species richness, total species richness, and percent cover by stratum for the Grand Canyon springs study sites, Grand Canyon, Arizona.

<b>Variable</b>	<b>Stratum</b>	<b>CCS</b>	<b>EGS</b>	<b>Burro Spr</b>	<b>PCS</b>	<b>PHS</b>	<b>MCS</b>	<b>HCS</b>	<b>HCG</b>	<b>EBS</b>	<b>RAS5</b>	<b>MAS</b>
Number of Species	GC	28	24	19	18	15	21	13	10	8	14	23
Number of Species	SC	17	15	17	12	19	11	7	10	8	4	13
Number of Species	TC	3	0	1	1	1	0	0	0	0	0	0
Number of Species	Total	45	38	36	30	35	32	20	20	16	18	36
Percent GC	GC	36.87	46.47	26.47	60.68	93.38	64.68	21.04	45.48	19.69	91.64	41.26
Percent SC	SC	52.96	40.24	83.21	48.81	95.54	22.24	47.42	21.76	33.77	19.37	40.45
Percent TC	TC	45.17	0.00	4.00	19.02	7.07	0.00	0.00	0.00	0.00	0.00	0.00

Hermit Creek, Royal Arch Creek, Matkatamiba Alcove springs) are extremely flood-prone, and are likely to undergo large seasonal changes in vegetation. Interannual variation in ground cover at Monument Creek Spring was extreme, varying from 12-73%, with an average of 37.3% cover and a standard deviation (31.0%) approaching the mean (Fig. 3). Extreme variation in vegetation cover will limit the ability of the NPS to related vegetation change to anthropogenic impacts, and better monitoring metrics than vegetation cover are needed.

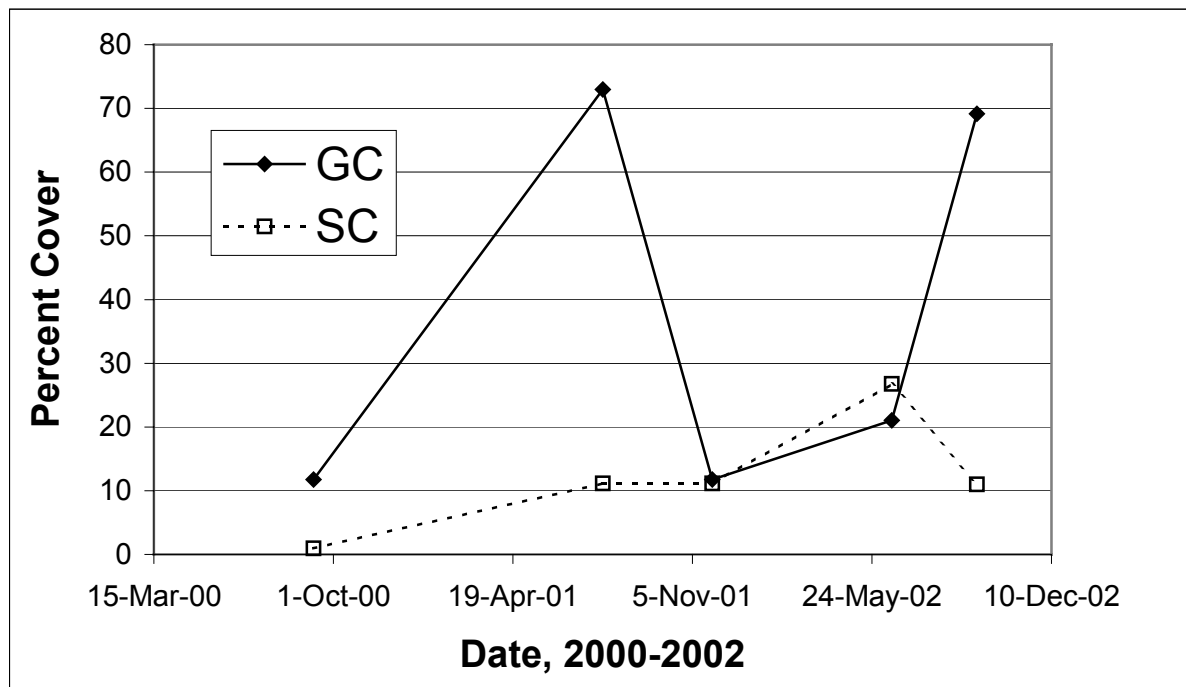


Fig. 3: Variation in percent ground and shrub cover at Monument Creek Spring, 2000-2002. GC – ground cover, SC – shrub cover (no tree cover exists at this site).

Average vegetation cover data among sites was multiplied by presence-absence frequency data among sites to provide a modified relative importance value (RIV) for each plant species (Table 7). This RIV indicates that several springs wetland plant species are dominant and sufficiently common for visual estimation of percent cover, which potentially may be useful for monitoring. These RIVs also indicate that several species were both widely distributed and locally abundant. Although cardinal monkeyflower (*Mimulus cardinalis*, RIV = 4.42) and maiden-hair fern (*Adiantum capillus-veneris*, 4.00) had the highest RIVs, they occurred primarily at bedrock-dominated springs that were subject to severe flood scouring. Monitoring the presence and cover of both species may be of use in long-term monitoring at sites such as Monument Creek and Hermit Creek springs. *Muhlenbergia asperifolia* (3.75) and common reed (*Phragmites australis*, 3.12) were widely distributed among the more alluvial sites. Canadian goldenrod (*Solidago canadensis*) occurred at all study sites, but was less locally abundant, and therefore had a somewhat lower RIV (1.82). A great many native subdominant taxa were detected (Table 7), but of the non-native species, only *Bromus rubens* and *B. rigidus* (cheatgrasses) had RIVs >0.4. These two abundant winter annual species are threats because they may increase fire frequency by providing much more dead ground cover during early summer.

Table 7: Ranked modified relative importance value (RIV) of plant species by stratum at the Grand Canyon springs study sites, Grand Canyon, Arizona. RIV was calculated as (percent frequency x total mean percent cover) across sites, divided by 100. Native status: N – native, E- exotic (note that in some cases the native status is unclear).

Genus	Species	Stratum	% Freq	Total Mean %Cover	Rel IV (Freq x Mean %Cov	Native Status
<i>Mimulus</i>	<i>cardinalis</i>	GC	54.55	8.10	4.4160	N
<i>Adiantum</i>	<i>capillus- veneris</i>	GC	63.64	6.28	3.9952	N
<i>Muhlenbergia</i>	<i>asperifolia</i>	GC	81.82	4.58	3.7472	N
<i>Phragmites</i>	<i>australis</i>	GC	36.36	8.57	3.1168	N
<i>Solidago</i>	<i>canadensis</i>	GC	100.00	1.82	1.8201	N
Moss	sp	GC	81.82	1.01	0.8256	N
<i>Typha</i>	<i>domingensis</i>	GC	36.36	1.81	0.6595	N
<i>Bromus</i>	<i>rigidus</i>	GC	36.36	1.46	0.5324	E
<i>Bromus</i>	<i>rubens</i>	GC	63.64	0.68	0.4321	E
<i>Carex</i>	<i>hystricina</i>	GC	36.36	0.92	0.3357	N
<i>Andropogon</i>	<i>glomeratus</i>	GC	18.18	1.76	0.3202	N
<i>Agrostis</i>	<i>stolonifera</i>	GC	27.27	1.16	0.3172	E
Unk. grass	perennial	GC	36.36	0.47	0.1696	N
<i>Thelepodium</i>	<i>integrifolium</i>	GC	36.36	0.42	0.1515	N
<i>Imperata</i>	<i>brevifolia</i>	GC	18.18	0.78	0.1424	N
<i>Cirsium</i>	<i>neomexicanum?</i>	GC	54.55	0.18	0.0962	N
<i>Carex</i>	<i>nebraskensis</i>	GC	9.09	1.05	0.0957	N
<i>Polypogon</i>	<i>monspeliensis</i>	GC	9.09	0.91	0.0832	N
<i>Conyza</i>	<i>canadensis</i>	GC	9.09	0.70	0.0635	N?
<i>Dichanthelium</i>	<i>acuminatum</i>	GC	27.27	0.23	0.0614	N
<i>Pleuraphis</i>	<i>rigidus</i>	GC	9.09	0.67	0.0612	N
<i>Stipa</i>	<i>speciosum</i>	GC	18.18	0.31	0.0557	E
<i>Solanum</i>	sp.	GC	18.18	0.29	0.0532	N
<i>Oenothera</i>	<i>hookeri</i>	GC	27.27	0.18	0.0496	N
<i>Cladophora</i>	<i>glomerata</i>	GC	18.18	0.27	0.0485	N
<i>Vicia</i>	<i>americana</i>	GC	18.18	0.26	0.0468	N
<i>Schenoplectus</i>	<i>acutus</i>	GC	9.09	0.50	0.0457	N
<i>Baccharis</i>	<i>emoryi (seedling)</i>	GC	18.18	0.25	0.0452	N
<i>Carex</i>	<i>aquatilis</i>	GC	18.18	0.24	0.0445	N
<i>Chara</i>	sp.	GC	9.09	0.43	0.0390	N
<i>Calamagrostis</i>	<i>scopulorum</i>	GC	9.09	0.40	0.0363	N
<i>Lactuca</i>	<i>seriola</i>	GC	27.27	0.13	0.0344	E
<i>Carex</i>	<i>geophila</i>	GC	18.18	0.19	0.0342	N
<i>Aster</i>	sp.	GC	18.18	0.19	0.0342	N
<i>Bothriochloa</i>	<i>barbinoides</i>	GC	9.09	0.36	0.0331	N
<i>Schizachyrium</i>	<i>scoparium</i>	GC	18.18	0.16	0.0283	N
<i>Bromus</i>	<i>tectorum</i>	GC	27.27	0.10	0.0271	E
<i>Astragalus</i>	<i>lentiginosus</i>	GC	18.18	0.14	0.0249	N
<i>Epipactus</i>	<i>gigantea</i>	GC	27.27	0.08	0.0220	N

Genus	Species	Stratum	% Freq	Total Mean %Cover	Rel IV (Freq x Mean %Cov	Native Status
<i>Rorippa</i>	<i>nasturtim-aquaticum</i>	GC	18.18	0.12	0.0217	E
<i>Elymus</i>	<i>canadensis</i>	GC	9.09	0.23	0.0213	N
<i>Clematis</i>	<i>lingusticifolia</i>	GC	18.18	0.11	0.0208	N
<i>Lobelia</i>	<i>cardinalis</i>	GC	27.27	0.07	0.0191	N
<i>Equisetum</i>	<i>hymale x laevigatum</i>	GC	27.27	0.06	0.0167	N
<i>Sporobolus</i>	<i>flexuosus</i>	GC	18.18	0.09	0.0155	N
<i>Elymus</i>	<i>cinereus?</i>	GC	9.09	0.17	0.0153	E
<i>Carex</i>	<i>atherodes?</i>	GC	9.09	0.17	0.0150	N
<i>Carex</i>	<i>aurea</i>	GC	9.09	0.15	0.0138	N
<i>Aquilegia</i>	<i>chrysantha</i>	GC	18.18	0.04	0.0073	N
<i>Pleuraphis</i>	<i>jamesii</i>	GC	9.09	0.08	0.0070	N
<i>Poa</i>	<i>pratensis</i>	GC	9.09	0.06	0.0054	E
<i>Maurandya</i>	<i>antirrhinifolium</i>	GC	27.27	0.02	0.0052	N
<i>Aristida</i>	<i>glauca</i>	GC	18.18	0.03	0.0051	N
<i>Bromus</i>	<i>sp.</i>	GC	9.09	0.06	0.0050	E
<i>Carex</i>	<i>sp.</i>	GC	9.09	0.05	0.0046	N
<i>Muhlenbergia</i>	<i>porteri</i>	GC	9.09	0.05	0.0042	N
<i>Hordeum</i>	<i>jubatum</i>	GC	9.09	0.04	0.0032	E
<i>Macraenthera</i>	<i>canescens?</i>	GC	9.09	0.03	0.0028	N
<i>Castelleja</i>	<i>sp.</i>	GC	9.09	0.03	0.0028	N
<i>Artemesia</i>	<i>ludoviciana</i>	GC	36.36	0.01	0.0024	N
<i>Bouteloua</i>	<i>curtipendula</i>	GC	18.18	0.01	0.0023	N
<i>Apocynum</i>	<i>canabinum</i>	GC	9.09	0.02	0.0017	N
Algae	Algae spp	GC	9.09	0.02	0.0016	N
<i>Verbascum</i>	<i>thapsus</i>	GC	9.09	0.02	0.0014	E
<i>Carex</i>	<i>specuicola</i>	GC	9.09	0.01	0.0013	N
<i>Sonchus</i>	<i>asper</i>	GC	18.18	0.01	0.0012	E
Unknown dicot sds	<i>sp.</i>	GC	27.27	0.00	0.0011	N
<i>Tamarix</i>	<i>pentandra</i>	GC	9.09	0.00	0.0004	E
<i>Mentzelia</i>	<i>albicaulis</i>	GC	9.09	0.00	0.0004	N
<i>Mentha</i>	<i>arvensis</i>	GC	9.09	0.00	0.0003	N
<i>Sidalcea?</i>	<i>sp.</i>	GC	9.09	0.00	0.0001	N
<i>Gnaphapium</i>	<i>chilense</i>	GC	9.09	0.00	0.0000	N
<i>Nicotina</i>	<i>obtusifolia</i>	GC	9.09	0.00	0.0000	N
<i>Poa</i>	<i>fendleriana</i>	GC	9.09	0.00	0.0000	N
<i>Juncus</i>	<i>bufonius</i>	GC	18.18	0.00	0.0000	N
<i>Sporobolus</i>	<i>contractus</i>	GC	9.09	0.00	0.0000	N
<i>Lepidium</i>	<i>sp.</i>	GC	9.09	0.00	0.0000	N
<i>Centaurium</i>	<i>calycosum</i>	GC	9.09	0.00	0.0000	N
<i>Acourtia</i>	<i>wrightii</i>	GC	9.09	0.00	0.0000	N
<i>Baccharis</i>	<i>salicifolia</i>	GC	9.09	0.00	0.0000	N
<i>Hedeoma?</i>	<i>sp.</i>	GC	9.09	0.00	0.0000	N
<i>Macraenthera</i>	<i>sp.</i>	GC	9.09	0.00	0.0000	N
<i>Datura</i>	<i>wrightii</i>	GC	9.09	0.00	0.0000	N

				Total Mean	Rel IV (Freq x	Native
Genus	Species	Stratum	% Freq	%Cover	Mean %Cov	Status
<i>Sphaeralcea</i>	<i>ambigua?</i>	GC	9.09	0.00	0.0000	N
<i>Baccharis</i>	<i>emoryi</i>	SC	72.73	6.13	4.4591	N
<i>Cercis</i>	<i>orbiculata</i>	SC	63.64	6.11	3.8877	N
<i>Iva</i>	<i>acerosa</i>	SC	45.45	7.33	3.3328	N
<i>Cladium</i>	<i>californicum</i>	SC	27.27	6.37	1.7378	N
<i>Brickellia</i>	<i>longifolia</i>	SC	81.82	1.38	1.1281	N
<i>Fraxinus</i>	<i>anomala</i>	SC	63.64	1.60	1.0195	N
<i>Rhus</i>	<i>trilobata</i>	SC	63.64	1.19	0.7557	N
<i>Nolina</i>	<i>microcarpa</i>	SC	36.36	1.98	0.7217	N
<i>Salix</i>	<i>exigua</i>	SC	45.45	1.34	0.6092	N
<i>Vitis</i>	<i>arizonica</i>	SC	18.18	2.07	0.3766	N
<i>Acacia</i>	<i>greggii</i>	SC	36.36	0.94	0.3401	N
<i>Agave</i>	<i>utahensis</i>	SC	63.64	0.49	0.3115	N
<i>Populus</i>	<i>fremontii</i>	SC	27.27	0.94	0.2550	N
<i>Ptelea</i>	<i>trifolium</i>	SC	27.27	0.65	0.1781	N
<i>Salix</i>	<i>gooddingii</i>	SC	18.18	0.93	0.1690	N
<i>Fallugia</i>	<i>paradoxa</i>	SC	36.36	0.44	0.1600	N
<i>Baccharis</i>	<i>salicifolia</i>	SC	18.18	0.86	0.1563	N
<i>Gutierrezia</i>	<i>sarothrae</i>	SC	81.82	0.19	0.1544	N
<i>Tamarix</i>	<i>pentandra</i>	SC	27.27	0.54	0.1466	E
<i>Baccharis</i>	<i>sergiloides</i>	SC	36.36	0.35	0.1272	N
<i>Isocoma</i>	<i>acredeni</i>	SC	27.27	0.36	0.0972	N
<i>Frangula</i>	<i>betulifolia</i>	SC	18.18	0.53	0.0970	N
<i>Rubus</i>	<i>discolor</i>	SC	9.09	0.95	0.0859	E
<i>Juniperus</i>	<i>osteosperma</i>	SC	18.18	0.33	0.0598	N
<i>Betula</i>	<i>occidentalis</i>	SC	9.09	0.42	0.0378	N
<i>Flaveria</i>	<i>mcdougallii</i>	SC	9.09	0.33	0.0302	N
<i>Petrphyton</i>	<i>caespitosum</i>	SC	9.09	0.29	0.0262	N
<i>Ephedra</i>	<i>torreyana</i>	SC	27.27	0.07	0.0197	N
<i>Aster</i>	<i>sp.</i>	SC	18.18	0.11	0.0193	N
<i>Amelanchier</i>	<i>utahensis</i>	SC	18.18	0.10	0.0186	N
<i>Ephedra</i>	<i>nevadensis?</i>	SC	9.09	0.18	0.0163	N
<i>Chrysothamnus</i>	<i>nauseosus</i>	SC	18.18	0.08	0.0148	N
<i>Lycium</i>	<i>andersoni</i>	SC	18.18	0.07	0.0136	N
<i>Salix</i>	<i>laevigata</i>	SC	9.09	0.14	0.0129	N
<i>Cercocarpus</i>	<i>montanus</i>	SC	9.09	0.09	0.0083	N
<i>Galium</i>	<i>stellatum</i>	SC	18.18	0.03	0.0056	N
<i>Ephedra</i>	<i>viridis</i>	SC	9.09	0.03	0.0028	N
<i>Atriplex</i>	<i>canescens</i>	SC	9.09	0.03	0.0025	N
<i>Stanleya</i>	<i>pinnata</i>	SC	9.09	0.01	0.0010	N
<i>Garrya</i>	<i>flavescens</i>	SC	9.09	0.00	0.0003	N
<i>Artemesia</i>	<i>tridentata?</i>	SC	9.09	0.00	0.0000	N
<i>Opuntia</i>	<i>basalaris</i>	SC	9.09	0.00	0.0000	N
<i>Brickellia</i>	<i>californica</i>	SC	9.09	0.00	0.0000	N

				Total Mean	Rel IV (Freq x	Native
Genus	Species	Stratum	% Freq	%Cover	Mean %Cov	Status
<i>Chaetopappa</i>	<i>ericoides</i>	SC	9.09	0.00	0.0000	N
<i>Populus</i>	<i>fremontii</i>	TC	36.36	4.76	1.7302	N
<i>Salix</i>	<i>gooddingii</i>	TC	9.09	2.04	0.1853	N
<i>Juniperus</i>	<i>osteosperma</i>	TC	9.09	0.05	0.0041	N

## TASK #6: AQUATIC AND TERRESTRIAL FAUNA

### METHODS

#### Aquatic Macroinvertebrates

A variety of techniques were used to sample the native and non-native fauna in and around the selected springs during the 2000-2003 growing season (Appendix D). Dip netting, generalized kick netting, and/or spot sampling (where possible) were conducted. Aquatic invertebrates were collected at all sites. Surber or kicknet samples were collected at Cottonwood, Pipe, and Hermit springs, the other sites when sufficient water existed to allow such collections. Collection techniques followed those recommended by Borror et al. (1976) and Merritt and Cummins (1996). Larval holometabolous forms were reared, where possible. Habitat affinities were recorded for all specimens.

#### Terrestrial Macroinvertebrates

One or several individuals or diagnostic portions of arthropods and mollusks encountered were collected, and taxa observed were recorded as well. Sweep netting, spot collecting, and light sampling (where possible) was conducted. We used a portable black white light, operated for one hour/site after full dark to attract night-flying species at each site. To collect flying invertebrate species, we used a malaise trap (a passive sampler) and placed 12 or more 10 cm-wide colored pan traps at 3 m intervals around the study site during day and night.

#### Invertebrate Taxonomy and Enumeration

Invertebrate specimens were labeled and transported to the laboratory for preparation. Specimens were mounted on pins (e.g., mosquitoes, beetles, butterflies, and other hard-bodied forms), or in 70% EtOH (soft-bodied forms). Associated host plant and habitat affinities were recorded for all specimens. Specimens were sorted, initially identified to family, and subsequently to lower taxonomic levels, and counted. Invertebrate data were entered into Excel spreadsheets, and these data will be provided to the NPS and AWPf with the final report. Labeled and identified specimens are stored at Northern Arizona University's Department of Biological Sciences invertebrate collection or the Museum of Northern Arizona, with voucher specimens to be deposited with the National Park Service at the South Rim, if the NPS so desires. Invertebrate taxonomy follows Arnett (1987) and Merritt and Cummins (1996). Identification and enumeration of specimens was conducted, and we have identified most taxa to the genus or species.

#### Vertebrates

Upon initial arrival, the site was inspected for birdlife, wildlife sign and herpetofauna during a 30-minute survey. We walked through each study site during the day and early

nighttime hours searching for herpetofauna, during one or more day and night searches per site. In addition to observations, we live trapped small mammals at each site twice during the study (Appendix D).

## RESULTS

### Aquatic Invertebrates

We detected at least 93 aquatic invertebrate taxa, with numerous new records for Arizona and Grand Canyon National Park (Table 8, Appendix D). Several species of particular management significance are *Helichus*, especially *H. triangularis* (Coleoptera: Dropidae) appear to be common at springs sources and may serve as a useful indicator of flow perennality. *H. suturalis* was only found at East Grapevine Spring. We estimate that nearly 70% of the >80 aquatic beetles of the Grand Canyon region require springs or spring-fed streams, and occur in no other habitats. An isolated population of belostomatid giant water bugs (*Abedus h. herberti*) was found in Boucher Creek, and the ochterid bug (Hemiptera: Ochteridae, *Ochterus rotundus*) is only known from several Grand Canyon springs (including Royal Arch Creek) and central southern Mexico (Polhemus and Polhemus 1976). This species may warrant management attention (our specimens are still out for positive identification as of this writing). Several individuals of *Brechmorhoga mendax* (Libellulidae) collected at some of these springs (e.g., Monument and Hermit Creek springs) have a gunmetal blue face, an atypical feature for this taxon, and may be an endemic form. Stoneflies were oddly absent from these collections.

### Terrestrial Invertebrates

We identified at least 199 terrestrial invertebrate taxa, including several species new to science, new records for Arizona, many new records for Grand Canyon National Park, and several species of potential management significance (Table 8, Appendix D). We collected a *Protolophus* (Protolophidae) harvestman at East Boucher Spring, and a *Thiodina* salticid jumping spider near *T. sylvana* at Monument Creek Spring that are new to science. These new species are being taxonomically described. We gained considerable insight through this inventory on the distribution of the Grand Canyon endemic tiger beetle, *Cicindela hemorrhagica arizonae*, which occurs as a riparian obligate along perennial streams in the upper and middle Grand Canyon, particularly Hermit and Boucher creeks. No endangered landsnails were detected at these 10 springs, although an unusual population of Niobrara ambersnail (Succineidae: *Oxyloma h. haydeni*) exists at Indian Gardens Spring adjacent to Pumphouse Spring. This populations is genetically similar to the endangered Kanab ambersnail (*O.h. kanabensis*; Miller et al. 2000).

Among the 16 species of butterflies and skippers found at these 10 Grand Canyon springs, we detected four species not previously reported from Grand Canyon, including the hesperiid Arizona powdered-skipper (*Systacea xampa*), the endemic megathymid piute agave skipper (*Agathymus alliae piute*), and several butterflies, including the desert marble (*Euchloe lotta*) and the desert elfin (*Callophrys fotis*). Spring-fed riparian zones provide far richer habitat than do the surrounding landscape, a point well known for plants and birds (Stevens et al. 1977, Stevens and Ayers 2002), but less well recognized for invertebrates. Butterfly distribution clearly demonstrated the keystone role of springs ecosystem in this desert landscape. We repeatedly

Table 8: Aquatic and terrestrial invertebrate species identified from the Grand Canyon South Rim springs, 2000-2003.

ORDER	Family	Genus	Species	Terr. or Aquatic	CWS	EGS	BS	PCS	PHS	MCS	HCS	HCG	EBS	RAS	MAS	Taxonomist
ARAN	Agelenidae	<i>Ageliopsis</i>	sp.	T			obs									L.E. Stevens
ARAN	Agelenidae			T							X					S. Crews
ARAN	Gnaphosidae	<i>Drassyllus</i>	<i>insularis</i>	T	X											S. Crews
ARAN	Harvestman			T					X							S. Crews
ARAN	Linyphiidae	<i>Frontinella</i>	<i>communis</i>	T		X		X							X	S. Crews
ARAN	Linyphiidae	<i>Maso</i>	<i>navajo</i>	T				X								S. Crews
ARAN	Linyphiidae			T			X	X								S. Crews
ARAN	Liocranidae	<i>Agroeca</i>	sp.	T										X		S. Crews
ARAN	Liocranidae	<i>Drassinella</i>	sp.	T									X			S. Crews
ARAN	Lycosidae	<i>Allocosa</i>	<i>mokiensis</i>	T						X		X	X	X		S. Crews
ARAN	Lycosidae	<i>Arctosa</i>	<i>littoralis</i>	T								X				S. Crews
ARAN	Lycosidae	<i>Pardosa</i>	sp.	T	X					X						S. Crews
ARAN	Lycosidae	<i>Pardosa</i>	<i>sierra</i>	T	X			X								S. Crews
ARAN	Lycosidae	<i>Pardosa</i>	<i>steva</i>	T				X		X						S. Crews
ARAN	Lycosidae			T							X			X		S. Crews
ARAN	Philodromidae	<i>Philodromus</i>	<i>satullus</i>	T											X	S. Crews
ARAN	Philodromidae	<i>Tibellus</i>	sp.	T				X		X						S. Crews
ARAN	Philodromidae	<i>Tibellus</i>	<i>oblongus</i>	T					X							S. Crews
ARAN	Salticidae	<i>Metaphidippus</i>	<i>chera</i>	T								X				S. Crews
ARAN	Salticidae	<i>Phidippus</i>	sp.	T						X						S. Crews
ARAN	Salticidae	<i>Thiodina</i>	n. sp. nr. <i>sylvana</i>	T						X						S. Crews
ARAN	Salticidae			T				X							X	S. Crews
ARAN	Tetragnathidae	<i>Tetragnatha</i>	<i>versicolor</i>	T				X			X		X	X		S. Crews
ARAN	Tetragnathidae	<i>Tetragnatha</i>	sp.	T					X		X					S. Crews
ARAN	Theridiidae	<i>Crustulina</i>	<i>sticta</i>	T				X								S. Crews
ARAN	Thomisidae	<i>Misumenops</i>	sp.	T		X						X				L.E. Stevens
ARAN	Thomisidae	<i>Misumenops</i>	<i>californicus</i>	T											X	S. Crews
ARAN-Opiliones	Protolophidae	<i>Protolophus</i>	n. sp.	T									X			S. Crews
ARAN-Opiliones	Sclerosomatidae	<i>Leiobunum</i>	<i>townsendi</i>	T	X								X		X	S. Crews

[illegible]

ORDER	Family	Genus	Species	Aquatic	CWS	EGS	BS	PCS	PHS	MCS	HCS	HCG	EBS	RAS	MAS	Taxonomist
COL	Hydrophilidae	<i>Cymbiodyta</i>	<i>dorsalis</i>	A		X			X					X	X	R. Durfee
COL	Hydrophilidae	<i>Enochrus</i>	<i>aridus</i>	A						X						R. Durfee
COL	Hydrophilidae	<i>Hydrophilus</i>	<i>triangularis</i>	A											X	L.E. Stevens
COL	Hydrophilidae	<i>Tropisternus</i>	<i>ellipticus</i>	A							X			X		L.E. Stevens
COL	Meloidae	<i>Lytta</i>	<i>magister</i>	T				X								L.E. Stevens
COL	Melyridae	<i>Collops?</i>	sp.	T				X								L.E. Stevens
COL	Scarabaeidae	<i>Phyllophaga?</i>	sp.	T									X			L.E. Stevens
COL	Scarabaeidae	<i>Polyphyllum</i>	sp.	T				X								L.E. Stevens
COL	Tenebrionidae	<i>Cryptoglossa</i>	<i>suricata</i>	T								X				A. Novak
COL	Tenebrionidae	<i>Eleodes</i>	<i>carbonaria</i>	T					X							A. Novak
COL	Tenebrionidae	<i>Eleodes</i>	<i>extricata</i>	T									X	X		A. Novak
COL	Tenebrionidae	<i>Eleodes</i>	<i>longicollis</i>	T	X				X				X			A. Novak
COL	Tenebrionidae	<i>Eleodes</i>	<i>tenebrosa</i>	T									X	X		A. Novak
COL	Tenebrionidae	<i>Stenomorpha</i>	<i>sponsor</i>	T	X			X	X	X		X				A. Novak
DIP	Asilidae			T	obs	obs	obs	obs	obs	obs	obs	obs	obs	obs	obs	L. Stevens - obs
DIP	Bombyliidae			T	X	X	X	X	X	X	X	X	X	X	X	L.E. Stevens
DIP	Culicidae	<i>Aedes</i>	<i>epactius</i>	A									X		X	F.B. Ramberg
DIP	Culicidae	<i>Culiseta</i>	<i>incidens</i>	A	X						X		X	X		L.E. Stevens
DIP	Culicidae	<i>Culiseta</i>	<i>inornata</i>	A					X							F. Ramberg
DIP	Culicidae	<i>Psorophora</i>	sp.	A						X						F.B. Ramberg
DIP	Dolichopodidae			T	X	X	X	X	X	X	X	X	X	X	X	L.E. Stevens
DIP	Empididae			A	X					X	X					L.E. Stevens
DIP	Muscidae	<i>Musca</i>	sp.	T					X							L.E. Stevens
DIP	Muscidae	<i>Stomoxys</i>	<i>calcitrans</i>	T								X				L.E. Stevens
DIP	Simuliidae	<i>Simulium</i>	<i>arcticum</i>	A									X	X		L.E. Stevens
DIP	Syrphidae			T	X	X	X	X	X	X	X	X	X	X	X	L.E. Stevens
DIP	Tipulidae	<i>Tipula?</i>		A	X	X	X	X	X	X	X	X	X	X	X	L.E. Stevens
DIPL	Julidae	<i>Cylindroiulus</i>	sp.	T					X							R.M. Shelley
DIPL	Paradoxosomatidae	<i>Oxidus</i>	<i>gracilis</i>	T					X							R.M. Shelley
DIPL	Schizopetalidae	<i>Colactis</i>	<i>utorum</i>	T		X			X				X			R.M. Shelley
EPH	Baetidae	<i>Baetis</i>	<i>magnus</i>	A				X		X	X	X		X	X	R. Durfee
				Terr. or												
ORDER	Family	Genus	Species	Aquatic	CWS	EGS	BS	PCS	PHS	MCS	HCS	HCG	EBS	RAS	MAS	Taxonomist



HYM	Apoidea	<i>Hylaeus</i>	<i>episcopais</i>	T				X								L.E. Stevens
HYM	Apoidea	<i>Hylaeus</i>	<i>paraprosopis</i>	T		X										L.E. Stevens
HYM	Apoidea	<i>Lasioglossum</i>	<i>sisymbrii</i>	T				X								L.E. Stevens
HYM	Apoidea	<i>Megachile</i>	<i>coquilletti</i>	T			X									L.E. Stevens
HYM	Apoidea	<i>Megachile</i>	<i>palmensis</i>	T		X										L.E. Stevens
HYM	Apoidea	<i>Megachile</i>	<i>subanograe</i>	T				X								L.E. Stevens
HYM	Formicidae	<i>Campanotus</i>	sp.	T	X											L.E. Stevens
HYM	Formicidae	<i>Crematogaster</i>	sp.	T									X			S. Crews
HYM	Halictidae	<i>Agapostemon</i>	sp.	T	X			X								L.E. Stevens
HYM	Halictidae	<i>Dialictus</i>	sp.	T							X					T. Griswold
HYM	Halictidae	<i>Dialictus</i>	<i>tegulariformis</i>	T								X				L.E. Stevens
HYM	Megachilidae	<i>Osmia</i>	sp.	T	X	X										T. Griswold
HYM	Mutillidae	<i>Chyphotus</i>	<i>melaniceps</i>	T	X											J. Pitts
HYM	Mutillidae	<i>Dasymutilla</i>	<i>occidentalis</i>	T											X	L.E. Stevens
HYM	Mutillidae	<i>Dasymutilla</i>	<i>vestita</i>	T												J. Pitts
HYM	Mutillidae	<i>Odontophotopsis</i>	<i>inconspicua</i>	T									X			J. Pitts
HYM	Mutillidae	<i>Odontophotopsis</i>	<i>melicausa</i>	T	X							X				J. Pitts
HYM	Pompilidae	<i>Pepsis</i>	sp.	T				X		X						L.E. Stevens
HYM	Sphecidae	<i>Ammophila</i>	sp.	T			X									L.E. Stevens
HYM	Sphecidae	<i>Bembex</i>	sp.	T								X			X	L.E. Stevens
HYM	Sphecidae	<i>Microbembex</i>	<i>arggropleura</i>	T											X	L.E. Stevens
HYM	Sphecidae	<i>Sceliphron</i>	<i>caementarium</i>	T								X				L.E. Stevens
HYM	Sphecidae	<i>Tachytes</i>	<i>weneri</i>	T								X				T.Griswold
HYM	Sphecidae	<i>Trypoxylon</i>	<i>californicum</i>	T											X	F.D. Parker
HYM	Tiphiidae	<i>Acanthetropis</i>	<i>noctivaga</i>	T							X	X			X	J. Pitts
HYM	Tiphiidae	<i>Myzinum</i>	<i>frontalis</i>	T								X				J. Pitts
HYM	Tiphiidae	<i>Paratiphia</i>	<i>ephippiata</i>	T			X									J. Pitts
HYM	Tiphiidae	<i>Paratiphia</i>	sp.	T	X							X				J. Pitts
HYM	Tiphiidae	<i>Paratiphia</i>	<i>verna</i>	T			X									J. Pitts
HYM	Vespidae	? <i>Stenodynerus</i>	sp.	T			X									L.E. Stevens
				Terr. or												
<b>ORDER</b>	<b>Family</b>	<b>Genus</b>	<b>Species</b>	<b>Aquatic</b>	<b>CWS</b>	<b>EGS</b>	<b>BS</b>	<b>PCS</b>	<b>PHS</b>	<b>MCS</b>	<b>HCS</b>	<b>HCG</b>	<b>EBS</b>	<b>RAS</b>	<b>MAS</b>	<b>Taxonomist</b>
HYM	Vespidae	<i>Eumenes</i>	sp.	T			X									F.D. Parker
HYM	Vespidae	<i>Euodynerus</i>	sp.	T								X				T.Griswold



[illegible]

LEP	Pieridae	<i>Phoebis</i>	<i>senna</i>	T								X				L.E. Stevens
LEP	Pieridae	<i>Pieris</i>	<i>callidice</i>	T	X											L.E. Stevens
LEP	Pieridae	<i>Pontia</i>	<i>beckerii</i>	T	X											L.E. Stevens
LEP	Pieridae	<i>Pontia</i>	<i>occidentalis</i>	T	X											L.E. Stevens
LEP	Pieridae	<i>Pontia</i>	<i>protodice</i>	T	X			obs	obs		X	obs	obs	obs		L.E. Stevens
LEP	Pieridae	<i>Pontia</i>	<i>sisymbrii</i>	T	X											L.E. Stevens
LEP	Sphingidae	<i>Hyles</i>	<i>lineata</i>	T	X				X			X				L.E. Stevens
MEG	Corydalidae	<i>Corydalus</i>	sp.	A								X		X	X	L.E. Stevens
MEG	Raphidiidae	<i>Agulla?</i>	sp.	T	X	X										L.E. Stevens
MOLL	Cochlicopidae	<i>Cochlicopa</i>	<i>lubrica</i>	T	obs											L.E. Stevens
MOLL	Cochlicopidae	<i>Cochlicopa</i>	<i>lubrica</i>	T									X			L.E. Stevens
MOLL	Euconulidae	<i>Euconulus</i>	<i>fulvus</i>	T				X								E.G. North
MOLL	Euconulidae	<i>Euconulus</i>	<i>fulvus</i>	T	obs											L.E. Stevens
MOLL	Limacidae	<i>Derocerus</i>	<i>laevae</i>	T					X							L.E. Stevens
MOLL	Oreohelicidae	<i>oreohelix</i>	sp.	T												G. Oliver
MOLL	Oreohelicidae	<i>Sonorella (?)</i>	sp.	T									X			L.E. Stevens
MOLL	Physidae	<i>Physa or Physella</i>	sp.	A					X						X	L.E. Stevens
MOLL	Physidae	<i>Vallonia</i>	<i>cyclophorella</i>	T				X								E. G. North
MOLL	Pupillidae	<i>Gastrocopta</i>	<i>ashmuni</i>	T				X								E. G. North
MOLL	Succineidae	<i>Catinella</i>	sp.	T			X									E. G. North
MOLL	Succineidae	<i>Catinella</i>	vermeta	T	X											L.E. Stevens
MOLL	Valloniidae	<i>Vallonia</i>	sp.	T	obs											L.E. Stevens
MOLL	Zonitidae	<i>Glyphyalinia</i>	<i>indentata</i>	T					X				X			E.G. North
MOLL	Zonitidae	<i>Zonitoides</i>	<i>arboreus</i>	T					X							E.G. North
MOLL		<i>Mesovitria</i>	sp.	T	obs											L.E. Stevens
ODO	Aeshnidae	<i>Aeshna</i>	<i>multicolor</i>	A				X		X					X	L.E. Stevens
ODO	Aeshnidae	<i>Anax</i>	<i>walsinghami</i>	A								X				L.E. Stevens
				Terr. or												
<b>ORDER</b>	<b>Family</b>	<b>Genus</b>	<b>Species</b>	<b>Aquatic</b>	<b>CWS</b>	<b>EGS</b>	<b>BS</b>	<b>PCS</b>	<b>PHS</b>	<b>MCS</b>	<b>HCS</b>	<b>HCG</b>	<b>EBS</b>	<b>RAS</b>	<b>MAS</b>	<b>Taxonomist</b>
ODO	Aeshnidae	<i>Anax</i>	<i>junius</i>	A							obs					L.E. Stevens
ODO	Aeshnidae	<i>Anax</i>	<i>walsinghami</i>	A					X			obs				L.E. Stevens
ODO	Calopterygidae	<i>Archilestes</i>	<i>grandis</i>	A				X						X	X	L.E. Stevens
ODO	Calopterygidae	<i>Hetaerina</i>	<i>americana</i>	A				X	X		X	X		X		L.E. Stevens
ODO	Coenagrionidae	<i>Argia</i>	<i>jugens</i>	A								X	X	X	X	L.E. Stevens

ODO	Coenagrionidae	<i>Argia</i>	<i>nahuana</i>	A									X			L.E. Stevens
ODO	Coenagrionidae	<i>Argia</i>	<i>vivida</i>	A	X	X	X	X	X	X	X	X	X		X	L.E. Stevens
ODO	Coenagrionidae	<i>Argia</i>	<i>vivida</i>	A		obs		obs			obs	obs		obs		L.E. Stevens
ODO	Coenagrionidae	<i>Ischnura</i>	<i>perparva?</i>	A		X									X	L.E. Stevens
ODO	Coenagrionidae	<i>Telebasis</i>	<i>salva?</i>	A										X		L.E. Stevens
ODO	Libellulidae	<i>Brechmohoga</i>	<i>mendax</i>	A		X		X		X	obs	X				L.E. Stevens
ODO	Libellulidae	<i>Libellula</i>	<i>saturata</i>	A		obs		obs	obs			obs		obs	obs	L.E. Stevens
ODO	Libellulidae	<i>Paltothemis</i>	<i>lineatipes</i>	A				X	X	X	obs	X		X	X	L.E. Stevens
ODO	Libellulidae	<i>Pantala</i>	<i>hymenaea</i>	A	X											L.E. Stevens
ODO	Libellulidae	<i>Sympetrum</i>	<i>corruptum</i>	A	X							X				L.E. Stevens
ORT	Acrididae	<i>Schistocerca</i>	sp.	T									X			L.E. Stevens
ORT	Gryllidae	<i>Gryllus</i>	sp.	T	X									X		D. Lightfoot
ORT	Gryllidae	<i>Oecanthus</i>	sp.	T							X		X			L.E. Stevens
ORT	Tettigoniidae	<i>Capnobotes</i>	<i>fuliginosus</i>	T	X											L.E. Stevens
ORT	Tridactylidae	<i>Ellipes</i>	sp.	T	X											L.E. Stevens
OSTR	Ostracode	<i>Candona</i>	sp.	A		X										L. Haury
SCOR	Buthidae	<i>Centruroides</i>	<i>exilicauda</i>	T								obs				L.E. Stevens
SCOR	Vaejovidae	<i>Hadrurus</i>	<i>sculpturatus</i>	T		X							X			L.E. Stevens
SCOR	Valloniidae	<i>Vallonia</i>	<i>cyclophorella</i>	T			X									E. G. North
TRI	Helicopsychidae	<i>Helicopsyche</i>	sp.	A											X	D. Ruiter
TRI	Hydropsychidae	<i>Hydropsyche</i>	<i>oslari</i>	A				X	X							D. Ruiter
TRI	Hydropsychidae	<i>Hydropsyche</i>	sp.	A					X	X				X		D. Ruiter
TRI	Hydropsychidae	<i>Hydropsyche</i>	<i>(cockerelli?)</i>	A											X	D. Ruiter
TRI	Hydroptilidae	<i>Hydraptila</i>	<i>(arctia?)</i>	A										X		D. Ruiter
TRI	Hydroptilidae	<i>Leucotrichia</i>	sp.	A											X	D. Ruiter
TRI	Hydroptilidae	<i>Ochrotricia</i>	<i>arizonensis</i>	A						X						D. Ruiter
				Terr. or												
<b>ORDER</b>	<b>Family</b>	<b>Genus</b>	<b>Species</b>	<b>Aquatic</b>	<b>CWS</b>	<b>EGS</b>	<b>BS</b>	<b>PCS</b>	<b>PHS</b>	<b>MCS</b>	<b>HCS</b>	<b>HCG</b>	<b>EBS</b>	<b>RAS</b>	<b>MAS</b>	<b>Taxonomist</b>
TRI	Hydroptilidae	<i>Ochrotricia</i>	sp.	A										X		D. Ruiter
TRI	Limnephilidae	<i>Limnephilus</i>	<i>bucketti</i>	A				X								D. Ruiter
TRI	Limnephilidae	<i>Limnephilus</i>	<i>tulatus</i>	A	X										X	D. Ruiter
TRI	Limnephilidae	<i>Limnephilus</i>	sp.	A	X	X		X						X	X	D. Ruiter
TRI	Odontoceridae	<i>Marilia</i>	<i>flexuosa</i>	A				X								D. Ruiter
TRI	Philopotamidae	<i>Chimarra</i>	<i>ridleyi</i>	A				X		X			X	X	X	D. Ruiter

TRI	Philopotamidae	<i>Chimarra</i>	sp.	A								X				D. Ruiter
TRI	Philopotamidae	<i>Wormaldia</i>	<i>arizonensis</i>	A					X	X						D. Ruiter
TRI	Philopotamidae	<i>Wormaldia</i>	sp.	A					X	X						D. Ruiter
TRI	Polycentropidae	<i>Polycentropus</i>	<i>halidus</i>	A				X								D. Ruiter
TRI	Polycentropidae	<i>Polycentropus</i>	sp.	A							X			X	X	D. Ruiter
TRI	Polycentropidae	<i>Polycentropus</i>	<i>cernotina</i>	A				X								R. Durfee
TRI	Psychomyiidae	<i>Tinodes</i>	sp.	A						X	X			X		D. Ruiter
TRI	Rhyacophilidae	<i>Rhyacophila</i>	<i>rotunda group</i>	A										X		D. Ruiter
TRI	Trichoptera	<i>Leucotrichia(?)</i>	sp.	A						X						D. Ruiter

encountered vastly greater density and species richness of butterflies along spring-fed streams than in the surrounding desert landscape, as illustrated by these data from Pipe Creek Spring on 25 May 2003. There we observed a total species in a 1 km transect over the same duration. This represents a 4.3-fold higher species richness and >300-fold greater abundance of butterflies in spring-fed riparian habitat as compared to the surrounding desert upland.

### **Herpetofauna**

We detected a total of 6 amphibian and reptile species at the springs study sites (Table 9). The two common amphibians included the red-spotted toad (*Bufo punctatus*) and canyon treefrog (*Hyla arenicolor*). The former was more abundant along low-gradient spring-fed streams, such as Cottonwood Creek, East Grapevine, Pipe Creek, and Hermit Creek springs, while the latter was more abundant near spring sources in bedrock and cobble/boulder stream reaches, such as cliff-bound reaches of Cottonwood Creek, East Boucher, Hermit Creek, and Matkatamiba Alcove springs.

The lizards encountered were all typical of middle and low elevations for Grand Canyon (Table 9), and included side-blotched lizard (*Uta stansburiana*), tree lizard (*Urosaurus ornatus*), desert spiny lizard (*Sceloporus magister*), western whiptail (*Cnemidophorus tigris*), collared lizard (*Crotaphytus bicinctores*), and banded gecko (*Coleonyx variegatus*). We encountered Grand Canyon pink rattlesnakes (*Crotalus viridis abyssus*) at Burro Spring and Matkatamiba Alcove Spring.

### **Avifauna**

We detected at least 44 bird species at the springs studied here (Table 10). Avian use of these 10 springs was generally high, with primary use as water sources. A total of 18 (41%) of the bird species detected at springs were not observed in the adjacent desert uplands, similarly attesting to the keystone landscape function of these desert springs. In August 2000 (a drought year) we observed several dead first year western tanagers (*Piranga ludoviciana*) at several springs, especially Monument Creek Spring. We attributed this mortality to environmental stress on these probably inexperienced birds, which probably could not find the spring water in time, and died from dehydration after reaching the spring.

Neither southwestern willow flycatcher (*Empidonax trailii extimus*), yellow-billed cuckoo (*Coccyzus americanus*), nor any rail species were detected at any of these springs; however, at least one avian species of management concern was found. Mexican spotted owls (*Strix occidentalis*) were detected at Cottonwood Creek Spring, near East Boucher Spring, and in Matkatamiba Canyon. This species is of considerable management concern in the Park. In addition, we found an American dipper nest (*Cinclus mexicanus*) in Matkatamiba Creek, near the Matkatamiba Alcove Spring. This late April nest is the only one reported in Grand Canyon in a desert warmwater stream (Stevens et al. 1997).

### **Mammals**

Few mammals were detected through direct observation at the 10 springs, primarily because most desert mammals are nocturnal, and because larger mammals are wary of humans. We occasionally saw, or otherwise detected sign, of at least 2 ungulates (desert bighorn sheep and desert mule deer) and 2 other rodents (brushy-tailed woodrat and variegated rock squirrel). In addition, bats were repeatedly observed at all study sites, but we did not conduct bat-netting.



Table 9: Herpetofauna observed at the Grand Canyon South Rim springs study sites, Grand Canyon National Park, Arizona, 2000-2003.

Common Name	Scientific Name	Springs										
		CWS	EGS	BS	PCS	PHS	MCS	HCS	HCG	EBS	RAS	MAS
	<b>Herpetofauna Observed</b>											
Red-spotted toad	<i>Bufo punctatus</i>	4/24/00	10/22/00		5/24/03; 9/6/02	6/4/02	7/28/01		7/26/01; 9/24/01	9/22/02		
Canyon treefrog	<i>Hyles arenicolor</i>	4/24/00		3/22/03	5/24/03; 9/6/02	6/4/02		7/26/01	7/26/01; 9/24/01	4/2/02;10/1/02	9/27/01	5/3/03
Western whiptail lizard	<i>Cnemidophorus tigris</i>	X	X	X	X	X	X	X	9/24/01	X	X	X
Grand Canyon western rattlesnake	<i>Crotalus viridis abyssus</i>			9/24/01	9/6/02	X						
Collared lizard	<i>Crotaphytus bicinctores</i>								7/26/01;			
California kingsnake	<i>Lampropeltus getulus</i>									10/1/02		
Chuckwalla	<i>Sauromalus obsoletus</i>								7/26/01;			
Desert spiny lizard	<i>Sceloporus magister</i>		X			6/4/02			7/26/01; 9/24/01			
Tree lizard	<i>Urosaurus ornatus</i>										9/27/01	X
Side-blotched lizard	<i>Uta stansburiana</i>	X	X						9/24/01			5/3/03
Banded gecko	<i>Coleonyx variegatus</i>				5/3/03							

Table 10: Bird species detected by observation at 10 Grand Canyon springs, 2000-2003.

Common Name	Scientific Name	CWS	EGS	BS	PCS	PHS	MCS	HCS	HCG	EBS	RAS	MAS
Turkey Vulture	<i>Cathartes aura</i>				X							
Western Screech Owl	<i>Otis asio</i>	X			X							
Mexican Spotted Owl	<i>Strix occidentalis mexicanus</i>	X								X		X
Mourning Dove	<i>Zenaida macroura</i>				X				X			
Hairy Woodpecker	<i>Picoides villosus</i>	X										
Northern Flicker	<i>Colaptes cafer</i>				X					X		
Red-naped sapsucker	<i>Sphyrapicus nuchalis</i>				X							
BC Hummingbird	<i>Archilochus alexanrei</i>		X	X		X			X			
Common Name	Scientific Name	CWS	EGS	BS	PCS	PHS	MCS	HCS	HCG	EBS	RAS	MAS

BT Hummingbird	<i>Selasphorus platycercus</i>									X		
White-throated Swift	<i>Aeronautes saxatilis</i>		X									
Ash-throated Flycatcher	<i>Myiarchus cinerascens</i>	X			X	X						X
Say's Phoebe	<i>Sayornis sayi</i>	X	X	X			X					X
Western Wood Pewee	<i>Contopus sordidulus</i>				X				X			
Common Raven	<i>Corvus corax</i>	X	X	X	X	X			X			X
Scrub Jay	<i>Aphelocoma coerulescens</i>	X	X						X			
Pinyon Jay	<i>Gymnorhinus cyanocephalus</i>	X	X									
Plain Titmouse	<i>Baeolophus ridgwayi</i>								X			
Common Bushtit	<i>Psaltiriparus minimus</i>	X	N		X	X			X			
Bewick's Wren	<i>Thryomanes bewickii</i>	X			X	X						
Canyon Wren	<i>Catherpes mexicanus</i>					X		X	X			X
Rock Wren	<i>Salpinctes obsoletus</i>	X	X	X					X	X		X
Winter Wren	<i>Troglodytes troglodytes</i>										X	
Ruby-crowned Kinglet	<i>Regulus calendula</i>	X	X		X	X						
Blue-gray Gnatcatcher	<i>Polioptila caerulea</i>			X	X	X			X			
Lucy's Warbler	<i>Vermivora luciae</i>			X	X	X						X
MacGillivray's warbler	<i>Oporornis tolmiei</i>								X			
Yellow Warbler	<i>Dendroica petechia</i>					X						
Yellow-rumped Warbler	<i>Dendroica coronata</i>								X			
Yellow-breasted Chat	<i>Icteria virens</i>					X						
Warbler sp.	Warbler sp.	X										
American Dipper	<i>Cinclus mexicanus</i>								X			X
American Robin	<i>Turdus migratorius</i>					X						
Sage Thrasher	<i>Oreoscoptes montanus</i>				X							
Western Tanager	<i>Piranga ludoviciana</i>						X		X			
Summer Tanager	<i>Piranga rubra</i>					X						
Spotted Towhee	<i>Pipilo maculatus</i>	X		X	X	X	X					
Black-headed Grosbeak	<i>Pheucticus melanocephalus</i>	X							X			
Lesser Goldfinch	<i>Carduelis psaltria</i>	X		X	X							
House Finch	<i>Carpodacus mexicanus</i>	X	X		X				X	X	X	X
Dark-eyed Junco	<i>Junco hyemalis</i>	X	X			X						
<b>Common Name</b>	<b>Scientific Name</b>	<b>CWS</b>	<b>EGS</b>	<b>BS</b>	<b>PCS</b>	<b>PHS</b>	<b>MCS</b>	<b>HCS</b>	<b>HCG</b>	<b>EBS</b>	<b>RAS</b>	<b>MAS</b>
Rufous-crowned Sparrow	<i>Aimophila ruficeps</i>					X	X		X			

White-crowned Sparrow	<i>Zonotrichia leucophrys</i>	X				X						
Vesper Sparrow	<i>Poocetes gramineus</i>						X					
Black-throated Sparrow	<i>Amphispiza bilineata</i>								X			

Table 11: Mammal species detected by observation or sign at 10 Grand Canyon springs, 2000-2003.

Common Name	Scientific Name	Springs										
		CWS	EGS	BS	PCS	PHS	MCS	HCS	HCG	EBS	RAS	MAS
	<b>Mammals Observed</b>											
Bighorn sheep	<i>Ovis candensis</i>	3/26/03								10/1/02; 9/24/02	9/28/01	4/29/02; 5/3/03
Desert mule deer	<i>Odocoileus hemionus</i>		9/22/02			11/15/01	11/27/01		9/24/01			
Woodrat	<i>Neotoma</i> sp.					11/15/01						
Variegated rock squirrel	<i>Ammospermophilus variegatus</i>								9/24/01			



Small mammal live-trapping was conducted at all sites during spring and fall visits, using >50 Sherman live traps/night/site. All specimens were identified, sexed, weighed, and reproductive status recorded by date, and photographed for taxonomic purposes where necessary. All animal care and human health precautions were observed during these collections according to NPS regulations. All specimens were released unharmed. Observations were recorded in field books.

Live-trapping revealed that trap success varied widely, from 0-67.5%, with low trap success during and after drought years (2000 and 2002; Table 12). Springs support different assemblages and abundances of small mammal than exist at lower elevations (where rodent populations have been relatively well studied), or in the surrounding uplands. *Neotoma*, *Eutamias*, *Peromyscus* (especially *P. boyleyi*) were common at springs along the Tonto Platform, whereas *Peromyscus eremicus*, *Peromyscus crinitus*, and *Neotoma lepida* were more abundant along the Colorado River (Ruffner et al. 1978). *Peromyscus eremicus* and *Perognathus* species had higher relative abundance in adjacent uplands around springs than at the springs themselves. Springs may serve as low elevation refugia for some species that are otherwise found at higher elevations on the South Rim (e.g., brushy-tailed woodrat, chipmunks).

Table 12: Small mammal trapping dates and success at the Grand Canyon springs study sites, 2000-2003.

Site Name	Date	Traps Set	Failed Traps	No. Mammals Caught	Trap Success (%)
Burro Spring	24-Sep-01	60	13	16	34.0
Burro Spring	6-Sep-02	50	1	9	18.4
Cottonwood Creek Spring	30-Mar-01	59	2	4	7.0
Cottonwood Creek Spring	26-Oct-01	76	17	30	50.8
East Boucher Spring	1-Apr-01	56	6	5	10.0
East Boucher Spring	26-Sep-01	50	4	22	47.8
East Grapevine Spring	30-Mar-01	56	1	6	10.9
East Grapevine Spring	27-Oct-01	56	9	28	59.6
Hermit Gauge	15-Jun-02	50	3	6	12.8
Hermit Gauge	25-Sep-01	50	2	23	47.9
Matkatamiba Alcove Spring	30-Sep-01	60	1	4	6.8
Matkatamiba Alcove Spring	3-May-03	51	3	0	0.0
Monument Creek Spring	27-Nov-01	50	2	8	16.7
Monument Creek Spring	16-Jun-02	50	2	1	2.1
Pipe Creek Spring	24-Sep-01	60	10	12	24.0
Pipe Creek Spring	6-Sep-02	51	1	5	10.0
Pumphouse Spring	15-Nov-01	50	10	27	67.5
Pumphouse Spring	5-May-02	52	6	20	43.5
Royal Arch Creek Spring, Falls #5	28-Apr-02	142	6	6	4.4
Royal Arch Creek Spring, Falls #5	3-May-03	51	0	3	5.9

Table 13: Trapping success and captures of  $\geq 8$  small mammal species at springs study sites, Grand Canyon, Arizona, 2000-2003.

Species	No. Caught	% Caught
<i>Eutamias dorsalis</i>	1	0.4
<i>Neotoma albigula</i>	19	7.8
<i>Neotoma cinerea</i>	2	0.8
<i>Neotoma lepida</i>	2	0.8
<i>Perognathus formosus</i>	15	6.2
<i>Perognathus intermedius</i>	1	0.4
<i>Peromyscus boylei</i>	77	31.7
<i>Peromyscus crinitus</i>	19	7.8
<i>Peromyscus eremicus</i>	105	43.2
<i>Peromyscus maniculatus</i>	1	0.4
<i>Peromyscus sp?</i>	1	0.4

## TASK #7: VEGETATION – ENVIRONMENT RELATIONSHIPS

### INTRODUCTION

Environmental factors that strongly influence wetland and riparian vegetation and other elements of springs ecosystems include: water flow and geochemistry, geomorphology, aspect, biogeographic elements of patch (island) size, isolation, and beta and gamma diversity, successional time, anthropogenic activities on both sides of the spring aperture, and complex interactions among these factors and biota. One of the most important issues is the role of surface flow on the spring site, as flood disturbance is the primary driving variable in wetland and riparian plant assemblages (Campbell and Green 1968; Stevens et al. 1995).

To gain a better understanding of how these variables affect the springs under study in Grand Canyon, we conducted several analyses. However, all of the springs studied here are strongly affected by surface flooding, and have a relatively similar water chemistry and elevation, precluding analysis of those important factors on springs biota. Such analyses require a broader array of springs from throughout the region. Furthermore, human impacts from visitation were only conspicuous at Pumphouse Spring, precluding detailed analysis of that variable as well. Therefore, we analyzed this suite of springs for patterns of alpha and beta biodiversity, with primary emphasis on vegetation, for which distributional data are relatively well known (Phillips et al. 1987, Ayers et al. 1994). We also present data on aquatic invertebrates.

### METHODS

#### Alpha Diversity

We used simple linear regression to test the strength of major geomorphological variables (elevation, dip angle, aspect as percent north, and  $\log_{10}$  area) on the  $\log_{10}$ -transformed number of plant species at the springs study sites. This allowed us to test for both physical variable effects and the island biogeographic species-area relationship (the  $\log_{10}$ -transformed species richness against the  $\log_{10}$ -transformed spring area). This analysis also allowed us to adjust species richness in relation to area.

To assess the role of geomorphology on plant species richness, we ranked the springs on their susceptibility/frequency to flooding disturbance, based on observed flood frequency and intensity from 2000-2003. We ranked the sites according to the following scale: 1 = low, 2 = moderate, and 3 = highly flood disturbance intensity. We used the species-area relationship (Eq. 1, below) to calculate the area-adjusted species richness (adjusted S) for each study site, and then graphed those values in relation to the qualitative flood susceptibility scores.

### Beta Diversity

We determined the elevation distribution of all wetlands plant species from regional floras and compared the distribution of wetland and riparian plants at our study sites in Grand Canyon with those in the region to determine the extent to which these 10 springs supported unique plant assemblages. Given the flood-prone nature of most of these springs, we hypothesized that species composition would vary much from that of the overall region.

We tallied the number of aquatic invertebrate species encountered at each spring, and present those data as well, but the limited distributional data on aquatic invertebrate species limits our understanding of beta diversity for this large group.

## RESULTS

### Alpha Diversity

We found a relatively strong positive species-area relationship, as well as a relatively strong negative dip angle relationship among the four physical variables examined (Table 14). The number of plant species encountered at each spring varied positively as a function of the size of the spring area sampled, and negatively in relation to the geomorphic intensity of

Table 14: Slope, y-intercept, and coefficient of correlation of linear regressions of elevation, dip angle, aspect (as percent north), and  $\log_{10}$  area against the  $\log_{10}$ -transformed number of plant species at Grand Canyon springs.

Site	Elevation (m)	Mean Dip Angle	% North	$\log_{10} A$	$\log_{10} S$
CCS	1257	3.0	92.8	2.47	1.65
EGS	1100	6.0	79.4	2.66	1.58
BS	1120	3.0	45.0	3.49	1.56
PCS	1135	2.0	80.6	2.94	1.48
PHS	1170	6.0	73.9	2.29	1.54
MCS	1130	70.0	82.2	2.74	1.51
HCS	1170	80.0	92.8	2.25	1.30
HCG	900	5.0	91.7	2.46	1.30
EBS	1077	35.0	53.9	2.23	1.20
RAS	700	80.0	55.6	1.99	1.26
MAS	560	11.5	59.4	2.99	1.56
Slope	0.000	-0.003	0.001	0.030	---
Y-int	1.258	1.521	1.359	0.905	---
$R^2$	0.069	0.326	0.019	0.344	---

flooding disturbance. The species-area relationship for the springs studied here was:

$$\log_{10} S = 0.2097 \log_{10} A + 0.9051 \quad \text{Eq. 1}$$

where  $S$  = total plant species richness in the wetland and riparian habitats associated with the spring, and  $A$  is the area ( $\text{m}^2$ ) sampled ( $R^2 = 0.34$ ; Fig. 4). The highest adjusted  $S$  value (1.65) occurred at Cottonwood Creek Spring, where we sampled a relatively small patch area in relation to the overall drainage, which contained additional plant species. This somewhat reduced the correlation coefficient of the overall species-area relationship.

We also found a relatively strong negative relationship between dip angle and the number of species (Table 14). This relationship was:

$$\log_{10} S = -0.003 X + 1.5213 \quad \text{Eq. 2}$$

where  $X$  is the mean dip angle of the site ( $R^2 = 0.326$ ). Steeper dip angles exist at springs that emerge from bedrock fractures, such as occurs at Monument and Hermit Creek springs, where conditions are generally not conducive as plant habitat.

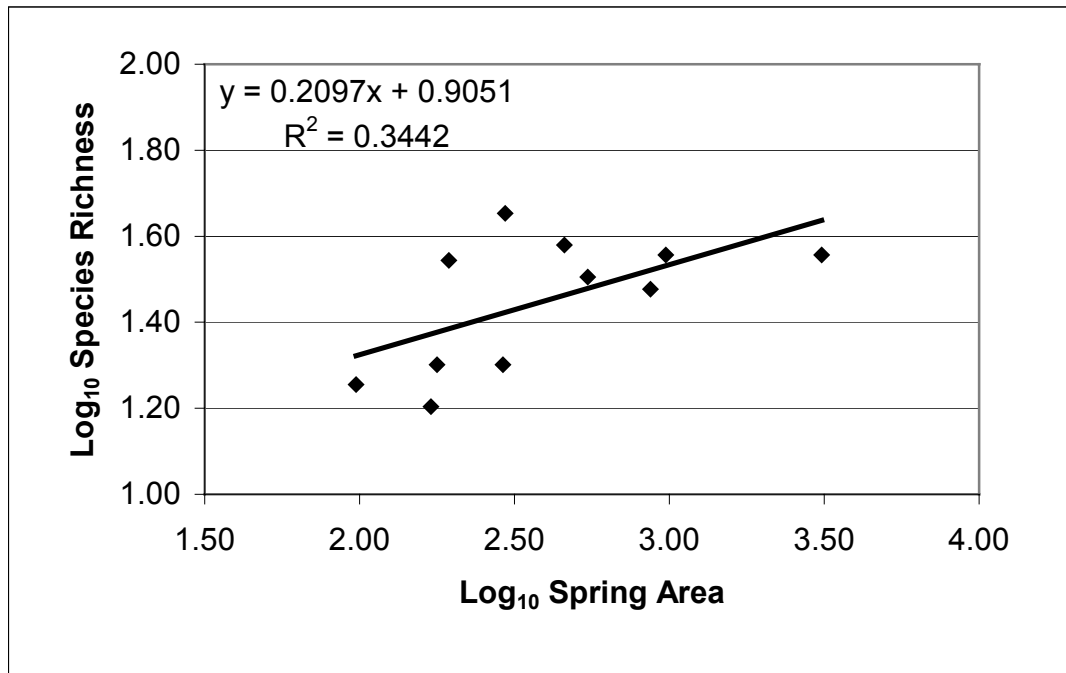


Fig. 4: Species-area relationship of plant species richness at Grand Canyon springs study sites.

Adjusted  $S$  was negatively related to flood disturbance intensity among the springs study sites (Fig. 5). In general, sites with low flood frequency disturbance intensity had higher area-adjusted species richness values. The lower adjusted  $S$  (1.39) among the low flood intensity sites occurred at Pumphouse Spring, a site that had significant visitation and wildlife (deer) disturbances. Variation in flood disturbance intensity within sites also contributed to higher than expected adjusted  $S$ : Monument Creek Spring was the most heavily flooded spring study site,

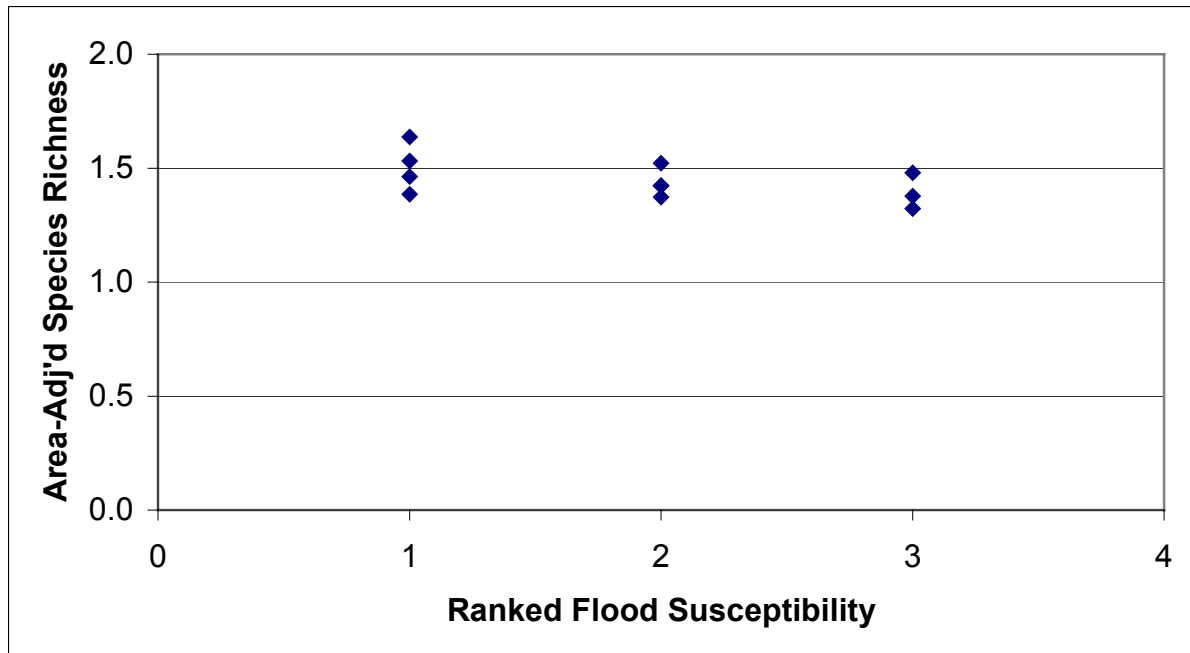


Fig. 5: Area-adjusted plant species richness as a function of qualitative flood disturbance intensity at Grand Canyon springs study sites.

as it exists at the base of a high pourout and sustains regular debris flow impacts as well as multi-annual flooding; however, it contains several species-rich patches on walls that are relatively protected from flood impacts, and therefore this site had a relatively high adjusted S (1.48). This analysis demonstrates that geomorphically-induced flood disturbance intensity decreases plant biodiversity at springs.

These analyses are in general agreement with our present understanding of slope and disturbance impacts on biodiversity (Huston 1994); however, we do not yet have clear metrics for understanding flood intensity at springs. We observed that flood disturbance intensity at several of our study sites (e.g., Monument and Hermit Creek springs) were extremely high, with regular scouring of these bedrock-dominated sites. That any vegetation persists at these sites is remarkable. What is less clear is the level of disturbance intensity at sites such as East Grapevine Creek, Burro Creek and Pumphouse springs, where conspicuous scouring did not take place during our study. Continued monitoring of these sites is needed to understand the longer-term responses of springs to relatively rare flooding events, and the riparian succession that takes place following such events.

### Beta Diversity

A total of 11 (10.2%) of the 108 plant species for which elevation range data were available exceeded their range limits at these 10 Grand Canyon springs (Table 14). These data indicate that although the springs studied did not contain many endemic plant species (*Flaveria macdougalii* in MAS was an exception), the plant assemblages at these springs are relatively unique. Six species ranges extended down to these springs from higher elevations, while five species were found beyond the top of their published elevational ranges at the springs. Cottonwood Creek, East Grapevine, and Pipe Creek Spring each supported four plant species

that existed beyond their normal elevational ranges, and Monument Creek Spring supported three such species.

Table 15: Plant species that exceed their upper (high) or lower (low) published elevation ranges at 10 Grand Canyon South Rim springs.

Genus	Species	CCS	EGS	BS	PCS	PHS	MCS	HCS	HCG	EBS	RAS5	MAS
<i>Acourtia</i>	<i>wrightii</i>						low					
<i>Baccharis</i>	<i>emoryi</i>	high	high	high	high	high		high	high	high		
<i>Baccharis</i>	<i>salicifolia</i>						high	high				
<i>Betula</i>	<i>occidentalis</i>						low					
<i>Carex</i>	<i>geophila</i>	low	low									
<i>Carex</i>	<i>aurea</i>		low									
<i>Carex</i>	<i>aquatilis</i>				high							
<i>Cladium</i>	<i>californicum</i>			high					high			
<i>Iva</i>	<i>acerosa</i>	high	high	high	high	high						
<i>Rubus</i>	<i>discolor</i>					low						
<i>Vicia</i>	<i>americana</i>	low			low							
Total	All	4	4	3	4	3	3	2	2	1	0	0

These data indicate that the effects of geomorphology on springs plant biodiversity is not simple. We hypothesized that highly protected, north-facing springs would support a higher proportion of upper elevation species. This was partially supported by the presence of *Betula occidentalis* at Monument Creek Spring, and high elevation *Carex* spp. and *Vicia* at Cottonwood Creek and East Grapevine springs. However, the study sites also contained nearly equal numbers of low elevation species that reached their highest elevations at these springs. Plant composition is complicated by longitudinal boundaries, affecting east-west distribution of species. For example, *Iva acerosa* reaches its western limit at Pipe Creek Spring, while *Flaveria macdougalii* reaches its eastern boundary at Colorado River Mile 136.5L. Additional data on more Grand Canyon springs, and data on the microclimates at these springs are needed to reveal environmental controls on springs wetland and riparian vegetation in Grand Canyon.

## TASK #7B: SPRINGS MONITORING PROTOCOLS

### Springs Ecosystem Monitoring

It is clearly within the purview of the NPS and Grand Canyon's enabling legislation to conserve and protect its springs ecosystems as resources of unparalleled aesthetic, recreational, educational, and scientific value. Desert springs are the most productive and biologically diverse terrestrial ecosystems, and commonly host 100-500-fold higher species concentrations than the surrounding landscapes. Unfortunately, springs are highly threatened through the West by a host of human activities, including livestock grazing, non-native species introductions, groundwater extraction, flow abstraction, and site modification. The small springs and seeps on the Tonto Platform in Grand Canyon are among the least altered springs remaining in the Southwest, and deserve considerable management and scientific attention. In addition, several large springs exist on adjacent Indian tribal lands (i.e., Blue Springs and Havasu Springs) and flow into the Park. These springs support important native fisheries, riparian vegetation, and extensive cultural resources. It would behoove the NPS to collaborate closely with the Navajo and Havasupai

tribes, respectively, to guarantee the continuity of flow and water quality from these large, ecologically important springs. At present protocols are being developed for several western Department of the Interior land units (Sada and Pohlmann 2003), and the NPS at Grand Canyon will be best served by continuing to collaborate in development of those protocols. Here, we describe overall and specific monitoring issues for Grand Canyon, and the current state of development of DOI springs monitoring protocols.

### **Overall Grand Canyon Springs Monitoring Issues**

Monitoring of South Rim springs flow, water quality, and biota is necessary to determine their condition their ecological health, long-term developmental trends, and threats in relation to visitor impacts and regional ground water extraction. The 10 springs investigated in this study provided considerable insight into the challenges and options for development of a long-term monitoring program. However, the 10 springs studied here were all (with the quasi-exception of Pumphouse Spring) surface flow-dominated systems, emerging for the most part from channel floors. Given the likelihood of annual or biennial scouring floods at these sites, these springs are likely to support weedy, generalist species or life stages, rather than microhabitat-adapted taxa, and vegetation cover and composition is likely to be highly dynamic. These considerations should be taken into account by the NPS if it desires to designate any of these springs as long-term monitoring sites.

We recommend development and testing of a cost-effective, time-flexible, and effective scientific monitoring protocol, including a data management system, that will help the NPS fulfill its land, wildlife and visitor management responsibilities (Shampine 1993, Beard et al. 1999). The NPS has developed guidelines for monitoring protocol development (<http://science.nature.nps.gov/im/monitor/protocol-guidelines.doc>), and these recommendations should be followed in developing the Grand Canyon springs monitoring protocols. These guidelines focus on the following issues:

**“Narrative.** The Protocol Narrative provides the rationale of why a particular resource or resource issue was selected for monitoring, gives background information concerning the resource or resource issue of interest, describes how monitoring results will inform management decisions, and discusses the linkages between this and other monitoring projects. The narrative gives an overview of the various components of the protocol, including measurable objectives, sampling design, field methodology, data analysis and reporting, personnel requirements, training procedures, and operational requirements. The narrative also summarizes testing and evaluation procedures involved in protocol design, and documents the history of decision-making that accompanied protocol development. This may be accomplished directly in the protocol narrative or by referencing related reports. Providing a history of protocol development and refinement will help ensure that periodic review and revision result in continued protocol improvement, rather than mere repetition of previous trials and comparisons.

**Standard Operating Procedures:** A series of SOPs present the details on how all aspects of the components described in the narrative will be carried out. The SOPs are likely to be updated more often than the protocol narrative. The SOPs should be written in the form of instructions, with step-by-step details of how to carry out each procedure. One of the SOPs should explain the procedure for making revisions to the protocol, and each protocol should include a log of its revision history, and archives of previous versions. The revision procedure should also specify

the need for and appropriate duration of an overlap period before new methods are adopted (Newell and Morrison 1993). Data sets should indicate which version of the protocol was being used when the data were collected, perhaps by including a field in the database to describe protocol version number.

***Supplementary Materials:*** Supplementary materials include example databases, supporting data and reports (e.g. GIS maps of soil strata, guild assignments of bird species), custom data management, data analysis or decision support tools (e.g. link to DISTANCE software to estimate detection functions), as well as materials that cannot easily be formatted and included as part of the digital protocol document (e.g. paper maps, photographs, binders of peer reviewers' comments and authors' responses)."

The protocols developed for Grand Canyon springs should include the following components:

- a) Flow monitoring
- b) Basic water quality (temperature, pH, specific conductance, major cations and ions, alkalinity, and nitrate-nitrogen). Chemical testing will be done in a certified water quality laboratory and according to standard protocols.
- c) Vegetation composition
- d) Vegetation patch distribution
- e) Aquatic invertebrates, with area-based quantitative sampling where possible
- f) Riparian invertebrates
- g) Any vertebrates detected during the survey, particularly endangered and endemic species.
- h) Anthropogenic impacts (construction, fencing, piping, other site alterations, trails, road impacts, etc.).

The present condition of a springs ecosystem is likely to strongly reflect not only the most recent flood or drought disturbance event, but also previous disturbances, as well as the vagaries of recolonization by plants and invertebrates. In other words, springs ecosystems of the types most common on the Tonto Platform are undergoing riparian succession, a process about which relatively little is known. Monitoring data may be acquired; however, without a framework in which to put such data or mapping efforts, there can be little understanding of the relevance of the observations. Vegetation cover may range from near zero immediately after a flood (e.g., Monument Creek Spring), to nearly 100% cover after several years. Composition may change dramatically through the successional process, with early stages little resembling late stages. Stream riparian succession was described by Campbell and Green (1968) as being suspended by flood disturbance. Grand Canyon springs with small drainages and generally low potential for large floods (e.g., Cottonwood Creek, East Grapevine, Burro, Pumphouse, East Boucher springs) generally retain their species composition after floods (many of the species at these sites are clonal, and the root mats are rarely scoured away completely). In contrast, Monument, Hermit, and Matkatamiba Alcove springs exist in drainages that regularly sustain large floods, and therefore the plant species composition and percent cover are likely to change dramatically from year to year. Monitoring biological variables other than bacteriology at these

sites requires understanding surface flow dynamics, the precise monitoring of which may be expensive, time consuming, and logistically challenging.

### **Questions to Guide Springs Monitoring**

The springs monitoring program for Grand Canyon should be designed to address the following seven questions in a credible, scientific fashion.

- 1) Is the spring's geomorphology consistent with its setting and history?
- 2) Is the spring's instantaneous flow at the time of monitoring consistent with its geomorphic condition and history?
- 3) Is the spring's water quality (at least water temperature, pH and specific conductance) at the time of monitoring consistent with its geomorphic condition and history?
- 4) Are the spring's plant composition, cover, and stage of successional development consistent with its geomorphology and history?
- 5) Are the spring's aquatic and terrestrial fauna (invertebrate and vertebrate) composition, and density consistent with its geomorphology, vegetation, and history?
- 6) What are the status and trends of each sensitive, endemic, and non-native species at the spring?
- 7) Is there evidence of anthropogenic impacts on the springs ecosystem integrity?

The Grand Canyon springs monitoring program should be efficient, cost-effective, and should provide timely (annual) information to Park managers. In the following discussion, we recommend monitoring of various springs variables, the appropriate protocols, and we suggest a schedule and budget for the timing of monitoring.

Regardless of the ultimate form that springs ecosystem monitoring takes in Grand Canyon National Park, there is a clear need for a consistent, carefully designed, and well-kept data management system. Development of this data management system is currently underway through the Northern Arizona Colorado Plateau Cooperative Ecosystem Studies Unit, and is planned for completion in 2004. Once again, we recommend that the NPS staff at Grand Canyon continue to collaborate with these other DOI offices to accomplish and implement these protocols.

### **Specific Monitoring Recommendations for Grand Canyon Springs**

**Monitoring Physical Variables:** Protocols for the measurement of surface water flow, water chemistry and other physical variables have been thoroughly described by the U.S. Geological Survey and the Environmental Protection Agency; however, measurement of these variables may require different strategies at springs, where flow may be diffuse or onto wet wall surfaces. Measuring the wetted area of the spring, or the area covered by precipitate may be options for wet wall seeps or seasonally intermittent springs, respectively.

**Monitoring Biological Variables:** Measurement of biological variables and anthropogenic impacts at surface-flow dominated springs ecosystems is far more difficult, because: each spring ecosystem supports different assemblages of plants and animals and monitoring one species may be appropriate at one site, but not at another; and because biological monitoring requires rather detailed expertise. Developing a separate monitoring program for each spring based on its unique features is both prohibitively complex and difficult to analyze. Nonetheless, the unique biota of each spring deserve attention, as they may serve as useful indicators of long-term change. In Table 15, we list the characteristics that appear to be unique at each of the 10 springs sites studied here, which the NPS may wish to consider using as indicators for monitoring.

Table 16: Unusual features of the 10 Grand Canyon springs.

Site	Unique Features and Characteristics
Cottonwood Creek Spring	Cottonwood tree growth, <i>Iva acerosa</i> , Nebraska sedge, high butterfly diversity, Mexican spotted owl in upper creek; desert stream and campground
East Grapevine Spring	<i>Helichus suturalis</i> ; standing pools of water; 3 high-elevation <i>Carex</i> spp., <i>Iva acerosa</i> , <i>Brechmorhoga mendax</i>
Burro Spring	<i>Cladium californicum</i> , cottonwood tree growth, Grand Canyon rattlesnake
Pipe Creek Spring	<i>Iva acerosa</i> , butterfly and Odonata diversity, <i>helleborine</i> orchid, cottonwood tree growth; desert stream
Pumphouse Spring	Cottonwood tree growth, Nebraska sedge, butterfly diversity
Monument Creek Spring	<i>Betula occidentalis</i> , white-flowering <i>Cercis orbiculata</i> , new <i>Thiodina</i> jumping spider; <i>Brechmorhoga mendax</i>
Hermit Creek Spring	White-flowering <i>Cercis orbiculata</i> , <i>Brechmorhoga mendax</i> , butterfly and Odonata diversitylarge desert stream with adjacent campground
East Boucher Spring	<i>Gyrinnis plicifer</i> whirligig beetles, <i>Helichus triangularis</i> , <i>Protolophus</i> harvestman, <i>Abedus herberti</i> in Boucher Creek; Mexican spotted owl in upper drainage; open pools of water
Royal Arch Creek falls#5 Spring	Maidenhair fern hanging gardens, pools, waterfalls and desert stream, <i>Ochterus rotundus</i> , Blue Cave
Matkatamiba Alcove Spring	Endemic MacDougall's flaveria, <i>Lobelia cardinalis</i> , <i>Hydrophilus triangularis</i> ; desert stream

**Monitoring Listed Species:** Mexican spotted owls (*Strix occidentalis lucida*) occur in several of the drainages associated with these springs, as do experimentally released California condor (*Gymnogyps californianus*). Monitoring protocols for these species are well established in accord with federal recovery plans (i.e., [http://mso.fws.gov/recovery\\_plan.htm](http://mso.fws.gov/recovery_plan.htm) for *Strix*, and U.S. Fish and Wildlife Service 1996). The NPS is currently monitoring its *Strix* and *Gymnogyps* populations carefully, using protocols coordinated with the U.S. Fish and Wildlife Service, the

Peregrine Fund, the Biological Resources Division of the U.S. Geological Survey, and other groups. Such surveying will continue as a part of the NPS's responsibilities.

**Monitoring Endemic Species:** Several endemic species may be worthy of monitoring attention, including *Flaveria macedougallii*, *Cicindela hemorrhagica arizonae*, and *Crotalus viridis abyssus*. MacDougall's flaveria can be monitored simply by noting the health and extent of the population at springs such as Matkatamiba Alcove Spring, 148R Spring, and other sites. Stand photographs from pre-designated photo points at annual intervals are sufficient to document the changing condition of these populations, provided the NPS is willing to review those photographs on a regular basis and interpret the condition of the population. Photographic documentation at 6-10 sites, coupled with on-going inventory of distribution, will be sufficient to maintain an understanding of this species population health.

The endemic tiger beetle can be monitored by further inventory efforts, annual site visits to Hermit, Boucher, and Monument Creeks in mid-July. During these site visits, the observer(s) should walk 6 or more predesignated 100 m belt transects and make density estimates.

Monitoring the Grand Canyon rattlesnake population is problematic because snakes are rarely encountered. The best monitoring protocol for this species is probably to encourage rangers, hikers, and other site visitors to photograph, with disturbing, every snakes encountered, noting the time of day, location, and habitat. The NPS would then be able to archive the photographs and eventually document distribution patterns of these apparently rare reptiles. Further research on movement patterns (such as that conducted on the Navajo Indian Reservation by Dr. Mike Douglas and his students) is warranted.

**Habitat Monitoring:** Grand Canyon springs are important as: 1) habitat for unique assemblages of native wetland and riparian plants; 2) as habitat for rare and unique aquatic and terrestrial invertebrates; and 3) as sources of water for wildlife and hikers. However, a long-term monitoring program for springs requires efficient use of personnel, time and equipment, particularly given the remote nature of Grand Canyon springs. Also, we consider a minimum of 10 yr of flow and biological data to be needed for scientific credibility of a monitoring program. Therefore, we recommend that the NPS involve 1-2 experts who hike to the springs 1-2 times/yr, conduct oblique photograph the sites, collect samples, and provide their data to an NPS data management system for archival. Flow measurements are probably best made in early spring, and biological sampling is best done in May and August-September, although no one month will provide a full array of species. Once every 3-5 yr, those data should be reviewed to determine trends. An annual aerial overflight for true color arial photography would be useful to document overall springs conditions. These photographs are most compelling if taken in September (after restrictions on California condor have been lifted, but still during the growing season).

### **Development of a Long-term Monitoring Program for Grand Canyon Springs**

We recommend that the NPS at Grand Canyon collaborate with Mohave and other National Park Service units on the Colorado Plateau, as they are actively discussing protocols for long-term monitoring of springs (Sada and Pohlmann 2003). The first draft of these criteria are presented in Table 16; however, additional attention should be devoted to site vegetation and the abundance of key indicators for the Grand Canyon springs (Table 17).

Table 17: Sada and Pohlmann (2003) draft Level I springs monitoring criteria. Record the following information at the spring source, and include the upper 50 m of aquatic habitat (at larger springs) in the survey. Spring runout brooks aquatic habitats should be monitored for the first 50 m.

1. Record the date that the spring survey is conducted
2. Identify personnel conducting this spring survey, and list a field note number.
3. Record the State where the spring being surveyed is located.
4. Record the County where the spring being surveyed is located.
5. Record the drainage basin where the spring is located. In the Great Basin, this consists of identifying the valley where the survey is being conducted, in regions with large basins, record the river basin. If in doubt about the location, record names of both the valley and river basin.
6. Record Township, Range, and quarter-section coordinates.
7. Record the 1:100,000 scale U.S. Geological Survey map that includes the spring/seep location, the 1:24,000 topographic map may also be recorded.
8. Record Global Position System location (NAD 27) of the spring/seep source. Either UTM's (to the nearest meter) or Latitude/Longitude (to the nearest second) may be used according to local convention. Computer programs are available to convert between these units. Also record PDOP to indicate the accuracy of these coordinates
9. Record whether or not the spring/seep can be accessed by vehicle. Record 'positive' if a road leads to the spring so that it can be reached by passenger car or 4 X 4, or 'negative' if no road exists. Exceptions to this are situations with historical road access but current access is blocked by flood, avalanche, etc. damage. In these situations cite that vehicle access is '+' and record in the notes that current access is blocked for the observed reason. The '+' notation is important because it is highly likely that the spring/seep was disturbed during historic vehicle access.
10. Record whether or not photos are taken of the spring/seep. Photos should be labeled by field note number, date, site name and Township, Range, quarter Section location. Photos should be taken using a digital camera, or slides and positive exposures should be scanned and digitally saved.
11. Record spring elevation in feet or meters (preferred). Measurement should be taken using GPS system (preferred). A Thomen altimeter (accuracy + 30 feet) may also be used but elevation should be calibrated from maps as frequently as possible during each day that fieldwork is conducted. Methods used to record elevation should be mentioned in comments portion of data sheet.

12. Record land ownership as U.S. Forest Service, U.S. Bureau of Land Management, Tribal, Military, Private, or other (e.g., State lands, U.S. Fish and Wildlife Service, municipality, etc., write out the name of the owner)
13. Record spring type as: Rheocrene (a spring that discharges into a defined channel), Limnocrene (a spring that discharges into a ponded or pooled habitat before flowing into a defined channel), or Helocrene (similar to a Limnocrene, but marshy and comparatively shallow, not an open pond or pool).
14. Estimate Spring Discharge in liters/minute. When possible, measure discharge by recording the length of time required to fill a container with a known volume. However, the small size of most arid land springs makes it difficult to accurately measure discharge. In most of these systems, it is not possible to capture all discharge or to measure current velocity using a meter or other methods. Also, daily and seasonal variation in discharge may be great, which suggests that estimates during a single survey may minimally describe long term discharge characteristics.
15. Estimate Spring Brook Length by measuring (or pacing) the distance (in meters) from spring source to the downstream extent of surface water.
16. Estimate average Water Depth (the vertical distance from substrate to water surface, in centimeters) that is found throughout the aquatic habitat.
17. Estimate the average Wetted Perimeter Width (the length of wetted contact between flowing or standing water and the spring brook bottom in a vertical plane at right angles to the direction of flow, in centimeters).
18. Measure Dissolved Oxygen Concentration (D.O., in mg/liter) using a field meter (e.g., YSY, Oakton, etc.). The meter should be kept clean, with fresh batteries, and calibrated daily following the manufacture's recommendation. All water chemistry parameters should be measured as close to the spring source as possible and in flowing water if available. The location of the measurements not taken at the source should be noted.
19. Measure Water Temperature. This measurement is easily taken with a meter used to measure D.O. or conductivity.
20. Measure Conductivity (electrical conductance, in  $\mu$ mhos or microsiemens) using a field meter (e.g., YSY, Oakton, etc.). The meter should be kept clean, with fresh batteries, and calibrated daily following the manufacture's recommendation.
21. Measure pH using a hand-held field meter that can be calibrated (such as Oakton Model, pHtestr2). The meter should be kept clean, with fresh batteries, and calibrated daily following the manufacture's recommendation. These meters generally have a limited life, and a backup meter should always be carried.

22. Qualitatively estimate the percent of Emergent Cover (vegetative, debris, or other material that arises within the wetted perimeter).
23. Qualitatively estimate the percent of Vegetative Bank Cover (live vegetation that covers spring brook banks within the riparian zone).
24. Qualitatively estimate Spring Brook Bank Incision. Rate banks as being incised when bank angle  $> 60^\circ$  from vertical, and not incised when bank angles are  $> 60^\circ$  from vertical. For spring brooks, bank incision is generally an indicator of stability and the absence of trampling activities.
24. Qualitatively estimate Spring Brook Bank Stability (the resistance or susceptibility of the spring brook channel and banks to erosion) as poor, medium, or good (on a scale of 1 to 3 with 1 being the most stable banks).
25. Qualitatively estimate the Percent of the Wetted Perimeter Covered by Watercress (*Rorippa nasturtium-aquaticum*).
26. Qualitatively estimate Substrate Composition using a Wentworth particle scale analysis, which describes the substrate by the proportional composition of materials, where materials are classified as: Fines ( $<1$  mm), Sand (1 mm - 5 mm), Gravel ( $>5$  mm - 80 mm), Cobble ( $>80$  mm - 300 mm), Boulder ( $>300$  mm), or bedrock. Size is defined as the minimum particle size of substrate as measured on a two-dimensional axis, as would pass through a substrate sieve.
27. Note presence of the following groups of animals, and identify the species, if possible: springsnails, fish, amphibians, pulmonates (e.g., Juga, Physa, etc.), amphipods, clams, and other notable animals.
28. Estimate Site Condition and identify influences causing disturbance. Sites should be categorized undisturbed, slightly disturbed, moderately disturbed, or highly disturbed by cultural or natural factors. These evaluations should follow these guidelines:
29. Springs can be disturbed by natural and cultural factors, which appear to have similar effects on aquatic and riparian communities. Natural and slightly disturbed springs have generally higher species richness and fewer non-native species than moderately and highly disturbed springs. Most springs in southern Nevada have been affected by cultural factors, including trampling by non-native animals (mostly cattle, wild horses and burros, and elk), diversion (often including a spring box that is placed into spring sources to capture water in a pipe and divert it to an off-site location), and recreation (which often includes diversion, trampling, and off-highway vehicle travel). Natural disturbance factors include fire, scouring floods (particularly at springs lying in arroyos), avalanche (high elevation springs), and drought. Ephemeral springs and seeps are considered as highly disturbed by the natural event of drought.

30. Site condition is assessed by categorizing the amount of disturbance that can be attributed to each cause of disturbance, which is scaled on a ranking from 1 (undisturbed) to 4 (highly disturbed) that are assigned according to the following criteria:
31. Undisturbed sites appear unaffected by historical or recent activity. Dry springs or intermittent seeps and springs are not classified as undisturbed because the disturbance of drought has an overwhelming influence on aquatic communities. These springs do not support non-native animal or plant taxa in riparian and aquatic communities, and they are 'reference conditions' that exemplify high quality habitat that can be compared to other, more disturbed sites. Sometimes it is difficult to determine whether these springs have ever been disturbed, or if they have naturalized from historical disturbance. Since most springs have been disturbed by some historical activity, totally undisturbed springs are believed to be rare. These springs are ranked disturbance category 1.
32. Slightly disturbed sites exhibit little evidence that vegetation or soil had been disturbed. Vegetation shows slight signs of browsing and foraging, and animal footprints and scat are prominent. These springs are ranked disturbance category 2.
33. Moderately disturbed sites exhibit evidence of recent disturbance. Vegetation covers > 50% of the spring brook banks, and at least 50% of natural discharge remains within the natural spring brook. Neither the spring or spring brook has been impounded, and non-native species do not dominate aquatic or riparian communities. These springs are ranked disturbance category 3.
34. Highly disturbed springs either have < 50% of their banks covered by vegetation, spring brooks containing < 50% of natural discharge, or they are impounded or dredged. Ephemeral springs are categorized as highly disturbed because of recent flow reduction. These springs are ranked disturbance category 4.
35. Human disturbance -- Qualitative estimate indicating the amount a spring has been disturbed by human-caused influences. Human-caused factors included impacts from management that include all factors attributed to the influence of humans. These consist of effects from non-native animals (e.g., cattle, wild horses, wild burros, and elk), diversion (municipal, domestic, and for livestock), and recreation. Multivariate analyses examined species-environmental relationships two ways, one by combining all human disturbances and the second by separating out each type of disturbance. Human Disturbance Categories were ranked as described above under 'Disturbance'.
36. Natural disturbance -- Qualitative estimate indicating the amount a spring has been disturbed by natural events. Fire, flood, and avalanche were the only natural disturbance factors observed in the Spring Mountains. Multivariate analyses examined species-environmental relationships two ways, one by combining all natural disturbances and the second by separating out each type of disturbance. Natural Disturbance Categories were ranked as described above under 'Disturbance'.

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